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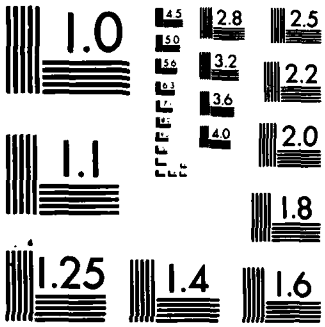

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UTILIZATION OF REFUSE DERIVED FUELS
BY THE UNITED STATES NAVY

Date: July 1983

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ABSTRACT

The Resource Conservation and Recovery Act and the Safe Drinking Water Act are forcing those in charge of landfills to adhere to more stringent operating standards. This, along with the growing scarcity of landfill availability, makes the use of landfills less desirable for solid waste disposal. As such, new disposal methods that are environmentally safe and economically practical must be found. One alternative, that is not really new but which has gained renewed interest, is incineration.

The Resource Conservation and Recovery Act also requires that government agencies should direct their installations to recover as many resources as possible. Therefore if incineration is to be implemented, heat recovery should be incorporated into the system. There are several processes available to convert raw refuse into a fuel for use in a heat recovery system. Refuse derived fuels (RDF) can be in the form of raw refuse, densified refuse, powdered refuse, gas, or pyrolytic oil. The only form of RDF that is economically feasible for systems desinged to process less than 200 TPD (tons per day) is raw refuse. Present technology has not advanced enough to make the other processes practical for small systems.

Most Navy bases generate far less than 200 TPD of solid waste and therefore the Navy has focused most of its attention on modular heat recovery inincerator (HRI) systems that utilize raw refuse as fuel.

Most of these systems have iether cyclone operators or electrostatic precipitators to control air particulate emmissions. Because of the small particle size (less than 20-30 um) being emitted by most HRI systems, electrostatic precipitators are more effective in controlling air particulate emmissions. Air particulate emission standards are not being exceeded, but the fly ash that accumulates in a cyclone separator or electrostatic precipitator

can produce a leachate whose lead and cadmium concentrations exceed the maximum allowable as specified in 40 CFR 261.24.

A HRI can theoretically produce steam at a lower cost than conventional methods being used today. These systems, however, have not demonstrated a great degree of reliability, availability, or maintainability. As a result production costs have exceeded predicted values. It is felt that the problem areas can be located and corrected. With this experience design changes can be made to improve operational reliability and with these improvements HRI systems can be an environmentally safe and economical means of solid wasted disposal.

INTRODUCTION

The American people generate municipal solid waste at the rate of approximately 3.0 lb per capita per day. This means more than 115 million tons of municipal solid waste is generated annually.(1) As Table-1 indicates, 88% of this waste is composed of combined household and commercial refuse.

Solid wastes from Naval installations however, is composed of mostly household and industrial refuse. It has been estimated that 76% of all the individual Navy complexes generate less than 14.3 tons per day (TPD) of refuse. This means that most of the Navy's solid waste management problems fall within this size range category.(2)

TABLE 1
Municipal Solid Waste Production in the United States (1)

	Measured weight lbs/person/day
Combined Household and Commercial Refuse	2.64
Street and Alley Cleanings	0.19
Tree and Landscaping Refuse	0.02
Park and Beach Refuse	0.01
Catch Basin Refuse	0.14
Total Pounds/person/day	3.00

Solid waste management involves decision making as to what method or methods should be utilized in disposing of the generated refuse. Based on the above discussion, the Navy's problems are much less severe than most metropolitan areas but they still must be dealt with in an intelligent manner.

By and far the most common method of disposal utilized by the Navy today, is landfill. Based on a survey of the Navy Public Work Centers, cost of disposal by landfill varies from $8 per ton to $42 per ton (Appendix B, Table B-1). But the cost is only one factor that must be considered. A survey of 38 Navy disposal sites was conducted and the results are shown in Table-2.
Based on this sample, 45% of all Navy sites must be expanded or

replaced within 7 years and only 24% have ample capacity to sustain operation for more than 15 years (2).

Landfill sites becoming less available, and those with continuing operation will be required to comply with more stringent environmental guidelines. This is a result of the Resource Conservation and Recovery Act (RCRA), and the Safe Drinking Water Act (SDWA). To meet these guidelines many of the landfills will have to be upgraded. The cost of the modifications required depends on site location and type of potential contamination. Table-3 gives an indication of some of the costs involved.

TABLE 2

REMAINING SITE LIFE FOR SELECTED NAVY SOLID WASTE ACTIVITIES

Remaining Site Life (Years)	Number of Sites	Percent of Total
less than 3	14	37
3 - 7	3	8
8 - 15	12	31
more than 15	9	24
TOTAL	38	100

TABLE 3

ESTIMATED COSTS OF UPGRADING NAVY LANDFILLS TO MEET VARIOUS RCRA REQUIREMENTS (In 1977 Dollars)

Requirement	Annualized Cost/Site*	Added Cost/Ton
Water Quality		
Environmentally sensitive area		
Wetlands, floodplains	7,660	1.96**
Permafrost	1,200	0.32**
Critical habitat	0	0**
Sole-source aquifer	1,200	0.31**
Surface water		
Nonpoint source controls	2,400	0.62
Ground water	10,500	2.69
Air Quality	800	0.21
Safety		
Gas controls	7,900	2.03
Fire	200	0.05
Access	400	0.10
Bird hazard	1,200	0.31
Disease Vectors	27,400	7.03
Aesthetics	700	0.18

*These estimates only include costs of meeting requirements not covered under other federal legislation.

**These estimates assume that upgrading is possible to meet RCRA requirements. Some facilities may be closed if contamination problems are found to be too extensive or impossible to control.

Since landfill sites are becoming more scarce and the operating costs of the available sites are continuing to increase, alternate methods of solid waste disposal must be pursued. One process that has been practiced for decades is incineration. By incinerating refuse, the volume that must be deposited in a landfill is greatly reduced. The bulk density of refuse at a landfill when buried under normal disposal conditions is 250-300 lb/yd^3 (3). Therefore, one ton of refuse requires 6.7-8 yd^3 of landfill volume. Table-4 provides a list of typical products of incineration and shows that 471 lb of solids per ton of refuse is produced that must be disposed of by separate means. The density of this unburned portion is 1000 lb/yd^3 (3). Therefore, 0.471 yd^3 is required for disposal of this residue, resulting from each ton of collected refuse. This represents a reduction of 93-94% of landfill volume required. This extends the life of any given landfill by an order of magnitude. With such a decrease in volume required and a correspondingly increase in landfill life, incineration must be considered as a viable alternative to landfill for refuse disposal.

Not only does the RCRA require compliance with more stringent guidelines in the operation of landfills, but it also encourages the recovery of materials and waste-derived fuels to the maximum extent practical at federal facilities (2). Therefore, if the Navy opts to utilize some form of incineration as the most environmentally sound method for refuse disposal, it must also pursue processes that will result in energy recovery of some type. This will require incineration systems that provide some means of heat recovery and/or processing systems that can convert refuse into a usable fuel.

TABLE 4

TYPICAL PRODUCTS OF INCINERATION (3)

	lb.per Ton of Refuse	Parts per Million by Volume
Stack Gases		
Nitrogen and Inert Gases	14,556.5	705,233
Oxygen	3,006.5	128,062
Water Vapor	1,482.8	112,389
Carbon Dioxide	1,738.0	53,542
Carbon Monoxide	5.7	279*
Hydrogen Chloride	6.2	232*
Organic Gases	6.8	123*
Nitric Oxide (NO)	1.7	78*
Sulfur Dioxide	3.0	62*
Total Gases	20,807.2	1,000,000
Solids, Dry Basis		
Residue from Grate	442.8	
Collected Fly Ash, 94% effc.	28.2	
Emitted Fly Ash, 6% Loss	1.8	
Total Solids	472.8	
Total	21,280.0	

*In furnace exit gases, typical values, capable of further reduction.

Refuse Derived Fuels

The use of refuse as a fuel originated in Europe where they have long cold winters and heating systems supplying large housing districts are prevalent.(1) Therefore, there is a large steam demand and a high energy cost. By utilizing refuse derived fuels (RDF), these costs can be somewhat alleviated.

RDF can be in the form of a solid, gas, or liquid. The solid RDF can be categorized as either raw municipal solid waste (MSW), densified RDF, coarse fluff RDF, or powdered RDF. Gas RDF can either ba low or medium Btu gas. Pyrolytic oil is the term generally associated with liquid RDF.

MSW is defined as "those obsolete products discarded by domestic, commercial and municipal consumers which would normally be deposited at municipal refuse disposal areas" (4). The value of this waste as a fuel is a function of moisture content and percent ash. Calorific value of the fuel varies in accordance with the following relationship (5).

$$B = Bo\left[1 - \frac{A + M}{100}\right] \text{ Btu/lb waste} \qquad (1)$$

Bo = calorific value of dry, inert free (DIF) refuse,

A = percent ash (non-combustible solids),

M = percent moisture.

Bo has been determined to equal 10,000 Btu/lb dry, inert free waste. This value and the above equation have been used to classify wastes to be incinerated by percent moisture content and heat available. The classifications have been given type numbers from 0 - 6 with characteristics as shown in Table-5 (5).

If more than one source of refuse is utilized and each source has different characteristics, the formula for an ideal mixture can be utilized to determine

TABLE 5 (U) CLASSIFICATION OF WASTES TO BE INCINERATED

Classification of Wastes Type	Description	Principal Components	Approximate Composition % by Weight	Moisture Content %	Incombustible Solids %	Btu Value/lb of Refuse as Fired	Btu of Aux.Fuel Per Lb of Waste to be included in Combustion Calculations	Recommended Min Btu/hr Burner Input per Lb Waste
0	Trash	Highly combustible waste, paper, wood, cardboard cartons, including up to 10% treated papers, plastic or rubber scraps; commercial and industrial sources.	Trash 100%	10%	5%	8500	0	0
1	Rubbish	Combustible waste, paper, cartons, rags, wood scraps, combustible floor sweepings; domestic, commercial, and industrial sources	Rubbish 80% Garbage 20%	25%	10%	6500	0	0
2	Refuse	Rubbish and garbage; residential sources	Rubbish 50% Garbage 50%	50%	7%	4300	0	1500
3	Garbage	Animal and vegetable wastes, restaurants, hotels, markets; institutional, commercial, and club sources	Garbage 65%	70%	5%	2500	1500	3000
4	Animal solids and organic wastes	Carcasses, organs, solid organic wastes; hospital, laboratory, abbattoirs, animal pounds, and similar sources	100% Animal and Human Tissue	85%	5%	1000	3000	8000 (5000 Primary) (3000 Secondary)
5	Gaseous, liquid or semi-liquid wastes	Industrial process wastes	Variable	Dependent on predominant components	Variable according to wastes survey	Variable according to wastes survey	Variable according to wastes survey	Variable according to wastes survey
6	Semi-solid and solid wastes	Combustibles requiring hearth, retort, or grate burning equipment	Variable	Dependent on predominant components	Variable according to wastes survey	Variable according to wastes survey	Variable according to wastes survey	Variable according to wastes survey

the additive properties (such as moisture content, heat value, and ash content) of the overall mixture. The formula is as follows (6):

$$Pa = \sum_{i=1}^{n} Mfi\ Pi$$

where Pa = additive property,

Mfi - mass fraction of component "i"

Pi = property of component "i".

Table - 6 lists the heating value of some components of refuse that can be utilized in the above equation in conjunction with equation (1) to determine the heat value of the mixture.

TABLE 6
REFUSE HIGHER HEATING VALUES (7)
(Dry weight basis)

Category	Standard HHV* (Btu/lb)	Measured HHV (Btu/lb)
Cardboard	7,791	7,862
Other paper	7,429	7,420
Food waste	8,162	9,042
Yard waste	7,282	8,006
Wood	8,253	8,423
Plastics	13,630	15,827
Textiles	8,793	8,452
Fines	3,457	4,568

* Kaiser, Elmer R., P.E., "Physical-Chemical Character of Municipal Refuse," Combustion Magazine, February 1977, pp. 26-28.

Estimates of solid waste composition in the northeastern United States and for Navy installations are shown in Table-7. Navy installations generate less glass, metals, and yard waste than municipalities, but produce more food waste on a percentage basis. The moisture content in both cases is between 20 and 30% and ash content is 10% for Navy waste and 23.5% for MSW. Based on this data the Navy raw refuse is probably closer to type 1 waste and has a heat value between 5000 Btu/lb and 6500 Btu/lb with 6300 Btu/lb being the calculated value utilizing equation (1).

TABLE 7

COMPOSITION OF SOLID WASTE

Type of Waste	Municipal Solid Waste in Northeast USA (8) *	Navy Solid Waste (9)
Paper Products	41.5	36
Mixed Office Waste		13
Wood	2.0	7
Yard Waste	12.9	5
Food Waste	16.2	21
Metals	9.4	5
Sludge		2
Glass	10.3	4
Other	7.7	7
Moisture Content	22.1	27
Total Ash	23.5	10
HHV-Btu/pound	4811	5050

* Percent as Discarded

Raw refuse can be utilized as a fuel in modular incinerators (0-150 tpd) or field erected incinerators (150-2000 tpd) (6). Since most Navy Bases generate less than 20 TPD the only logical choice for their utilization is modular incineration. A typical modular incineration system is shown in Figure 1. These units produce 3700 lb steam per ton of solid waste at a saturation pressure of 100-280 psig. No units are presently being used to generate electicity but it is estimated that 30-100 KWH/ton of solid waste could be realized (10).

One of the processes that has been utilized in an attempt to make refuse a more acceptable fuel is densification. Enhanced RDF is generally used in this process. Enhanced RDF is that which has been subjected to some form of processing to remove the major portion of fine, inert materials commonly inherent in the unscreened, shredded.air classified,light fraction (11). A typical processing scheme is shown in Figure 2.

dRDF has a heating value in the range of 6000-7000 Btu/lb. The moisture content varies from 0 to 10% and the ash content is in the range of 15-25% (10).

It has been co-burned with coal or separately as the only fuel in incinerators. dRDF has a lower fusion temperature and higher ash content than coal, which can result is ash handling, slagging, and clinkering problems (11). Several other problems have been encountered when dRDF has been utilized as the only fuel. An extreme amount of dust is generated during the fuel handling process. Inadequate distribution of fuel over the boiler grates has also been experienced causing a non-uniform bed depth, resulting in uneven burning and localized hot spots. The occurence of ignited organic particles being carried over with combustion gases into the cyclonic collectors causing smoldering and fires has also been observed (11).

The Air Force established some specifications for dRDF in their request for proposal (RFP) from suppliers of dRDF. Table 8 provides a comparison between the specifications requested and the average values of dRDF as determined by the Air Force. As shown, the average ash content is higher than that specified, which increases the chances of the problems discussed earlier to occur. The moisture content is also borderline, which will result in large evaporative heat losses. The Air Force also believes that pellet density, dRDF size distribution, ultimate fuel analysis (i.e. amount of H, C, N, O, and S in the fuel), volatile matter, ash analysis and ash fusion temperature, pellet biodegradation, and pellet integrity are important parameters in optimizing the storage, transport, and combustion of dRDF (11).

As stated earlier, dRDF can be burned as a sole source of fuel or co-burned with coal in a typical stoker boiler. From a Navy standpoint, however, a dRDF system is not feasible in the 0 - 40 TPD range and it has been estimated that a rate of 200 - 250 TPD is required for economic feasibility (10). Thus, for small generation systems, dRDF is not a practical alternative.

TABLE 8 PROPERTIES OF dRDF (11)

Property	Number of Data Points	Range	Average	Std. Dev.	Air Force dRDF Specifications
Heating Value, Btu/lb (dry)	14	6890-8431	7525	460	6500
Ash Content, percent (dry)	15	10-30	16.6	7.3	15
Moisture Content (percent)	15	6-28	19.3	6.6	20
Bulk Density (lb/ft^3)	3	25-30	27.7	2.5	35
Pellet Density (lb/ft^3)	2	35-74	I[a)]	I	None
-3/8" Fines (as received)	1	I	I	I	5
Volatile Matter, percent (dry)	8	60-77	66.9	6.8	None
Ultimate Analysis, percent (dry)					
H	5	5-6	5.8	0.4	None
C	5	31-43	37.6	4.8	None
N	5	0.4-3.0	1.1	1.1	None
O	5	23-41	35.2	7.1	None
S	6	0.1-0.3	0.2	0.1	None
Ash Analysis, percent (dry)					
SiO_2	2	28-47			None
Al_2O_3	2	10-31			None
NA_2O	2	4-7			None
CaO	2	5-15			None
Fe_2O_3	2	2-5			None
MgO	2	4-7			None
	2	0.1-0.9			None

a) = Data only available [illegible] rce ans was measured after shipment to the burn site.

Coarse fluff RDF is the least refined form of solid waste fuel used commercially. It is larger in size and contains more inorganic matter than other types of processed fuels. The use of this fuel is limited to grate fired incinerators. Because of the high inorganic content, the probability of slagging and clinkering is also increased and as a result, it has not been widely used. It to is not economically feasible when waste generation rate is below 200 - 250 TPD and therefore does not exhibit much promise for use by the Navy (10).

On the other end of the scale, powdered RDF is the most refined form of the solid fuels. The minimum waste generation rate of 200 - 250 TPD is also necessary to obtain economic feasibility with this type of fuel and this far exceeds the typical Naval Station production rate (10).

The production of gas and liquid fuels from refuse is accomplished by pyrolysis. Pyrolysis is generally referred to as destructive distillation, but is correctly defined as an irreversible chemical change brought about by the action of heat in an oxygen deficient atmoshpere (12). Pyrolysis of solid waste feed material produces CO, H_2, CO_2, hydrocarbons, and condesnsibles that are carried in the product gas and carbonaceous residue with gas phase constituents. Some of the more important reactions are as follows (13):

$$C + O_2 \rightarrow CO_2$$
$$C + CO_2 \rightarrow 2CO$$
$$C + H_2O \rightarrow CO + H_2$$
$$C + 2H_2 \rightarrow CH_4$$

The first reaction is highly exothermic, extremely rapid, and proceeds to completion with respect to oxygen disappearance. The second and third reactions are commonly referred to as the Boudouard reaction and the water gas reaction

respectively. These reactions are endothermic and are thermodynamically favored at temperatures over 700°C. The reactions are slow, however, and therefore are rarely at equilibrium in coal char systems at temperatures below 1100°C. The last reaction is highly exothermic and is favored at temperatures below 600°C (13).

Reaction rate tests were conducted at Princeton University utilizing newsprint from the New York Times and the Wall Street Journal, hardwood and softwood sawdust, and cow manure at nominal heating rates of 5°C/min., 10°C/min., 20°C/min., 50°C/min., and 100°C/min. The following general rate equation resulted (14):

$$\frac{dv}{dt} = K \quad (V^* - V)^n$$

$\frac{dv}{dt}$ = rate of weight loss (on a mass fraction basis)

V^* = Volatile weight fraction of the organic material

n = reaction order

$K = A \exp(-E/RT)$

A = frequency factor

E = activiation energy

R = universal gas constant

T = temperature (°K).

From this equation it is apparent that temperature and the initial volatile fraction of the organic material are important parameters in controlling the pyrolysis process.

It has been estimated that 90% of the energy content in the dry feed can be recovered and is in the form of gas or oil after exiting the pyrolysis process (15,1). The temperature of the exit gas is approximately 400 - 500°C with a heating value of 100 - 170 Btu/SCF. Natural gas as a heating value of 1000 Btu/SCF. High Btu RDF derived gas is that which has a heating value greater than or equal to 50% of the natural gas value; medium Btu gas has

a heating value greater than or equal to 25% of the natural gas value; and gas with a heating value which is less than 25% of the natural gas value is termed low Btu gas (1). So based on these definitions, most systems produce low to medium Btu gas. Table - 9 illustrates the variance that occurs both in component structure and heating value between different pyrolytic processes.

TABLE 9 PYROLYTIC GAS COMPOSITION OF DIFFERENT PYROLYSIS PROCESSES (10)

Component (% by volume)	Purox System	Enterprise System	Dual Fluidized Bed
H_2	26	1.19 - 4.06	19.58
CO	40	3.53 - 21.25	35.84
CO_2	23	14.80 - 36.36	16.73
CH_4	5	2.31 - 13.69	14.35
Other Hydrocarbons	1	6.07 - 14.18	9.08
N_2 and others	1	17.3 - 72.26	4.08
Heating value (Btu/SCF)	370	146 - 502	530

As with several of the other RDF processing systems, pyrolysis is not suitable for small systems. The process is highly technological and capital intensive (10). Also, the process is still in the developmental stage from a practical application standpoint. The city of Baltimore constructed a 1,000 ton/day plant in 1972 - 1975 time frame. This system had to be modified both in 1976 and 1978. It is now shut down for conversion to mass burning incineration (10). This illustrates even further that more research is needed before pyrolysis can be utilized on a wide scale basis for the production of RDF.

Table - 10 summarizes the properties of the RDF fuels. For small systems the only RDF fuel that appears to be a possible alternative is raw municipal solid waste. Unfortunately, of all the fuels, it has the least desirable properties. The heating value is 17% to 88% less than other RDF. The moisture

contents is 20% to 25% higher than densified and powdered RDF. The ash content is 5% to 15% higher than the other forms of RDF. The total volatile fraction is 20 to 40% less than other RDF. Bulk density of MSW is 20% to 33% less than the fluff forms of RDF and an order of magnitude less than densified or powdered RDF.

This means that a much larger quantity of MSW is required to produce the same heat output as other RDF and a larger percentage of this heat will be lost due to evaporation. The chances of clinkering and slagging in the boiler is greatly increased and storage requirements could be a significant problem. But with all its shortcomings, MSW is the most economical RDF for small systems. This is due to either the need for further technological development of the other processes or the high capital and operational costs of those processes. Table 11 provides a summary of combustion systems that should be used with MSW as well as other forms of RDF and the necessary generation rates in order to approach economic feasibility.

TABLE 10 Characteristics of Refuse Derived Fuels (10)

Characteristic	PROCESSING ALTERNATIVE Raw MSW	Coarse Fluff RDF	Fine Fluff RDF	Densified RDF	Physically Powdered RDF	Chemically Powdered RDF
Heating Valve (Btu/lb)	4,000-6,000	6,000-7,000	6,000-7,000	6,000-7,000	7,500-8,500	7,500-8,500
Moisture 20-40 content (%)	20-35	20-35	20-35	0-10	0-10	
Ash Content (%)	20-30	15-25	15-25	15-25	15-25	15-25
Total volatile (%)	40-60	65-80	65-80	65-80	65-80	65-80
Fixed carbon (%)	4 - 8	5 - 9	5 - 9	5 - 9	5 - 9	5 - 9
Carbon (%)	25-35	30-40	30-40	30-40	30-40	30-40
Hydrogen (%)	3 - 6	3 - 6	3 - 6	3 - 6	3 - 6	3 - 6
Nitrogen (%)	0.5-1.0	0.5-1.0	0.5-1.0	0.5-1.0	0.5-1.0	0.5-1.0
Sulfur (%)	0.1-0.5	0.1-0.5	0.1-0.5	0.1-0.5	0.1-0.5	0.1-0.5
Chlorine (%)	0.4-0.7	0.4-0.7	0.4-0.7	0.4-0.7	0.4-0.7	0.4-0.7
Bulk density (lb/ft^3)	2 - 4	3 - 5	3 - 5	30-35	25-30	25-30
Particle size distribution, largest (in)	10-15*	4 - 7	2 - 3	2 - 4	100 mesh	150 mesh

* Excludes oversize and bulky items.

TYPE OF RDF	TYPE OF COMBUSTION SYSTEM	APPLICABILITY REQUIREMENTS BASED ON ECONOMIC FEASIBILITY
Raw (Unprocessed) Solid Waste	Modular Incineration	0 - 150 TPD
	Field Erected Water Wall incineration	250 - 2000 TPD
Chemically Powered RDF	Suspension-fired Coal boiler (1)	minimum of 200 - 250 TPD
Coarse Fluff RDF	Modular Inceneration (2)	minimum of 200 - 250 TPD
	Solid Fuel Boiler (3)	minimum of 200 - 250 TPD
Densified RDF	Modular Incineration (2,4)	minimum of 200 - 250 TPD
	Solid Fuel Boiler (3,4)	minimum of 200 - 250 TPD
Physically Powered RDF	Suspension-fired Coal boiler (1)	minimum of 200 - 250 TPD

TABLE 11 RDF Fuel Types, Combustion Systems and Applicability Requirements

(1) RDF blended with pulverized coal

(2) Alone or mixed with raw MSW

(3) Alone or mixed with original fuel

(4) Ash handling system may have to be oversized.

FIGURE 1 RAW REFUSE MODULAR INCINERATION SYSTEM (10)

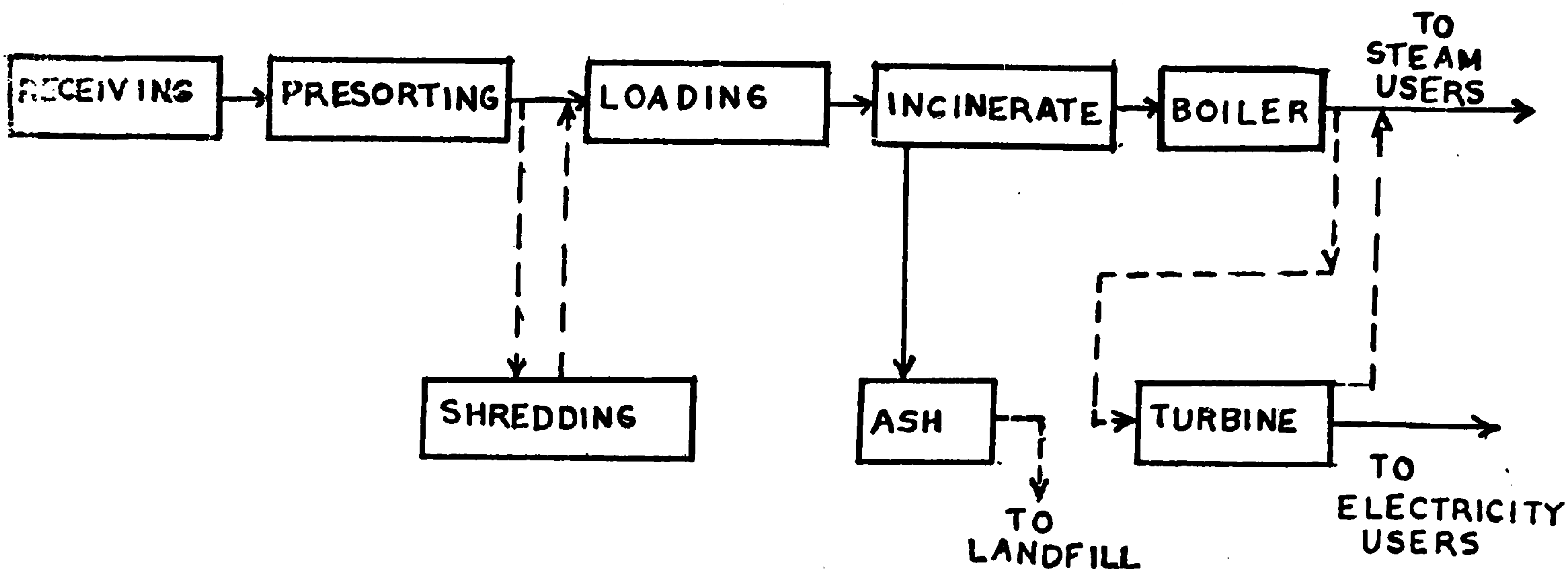
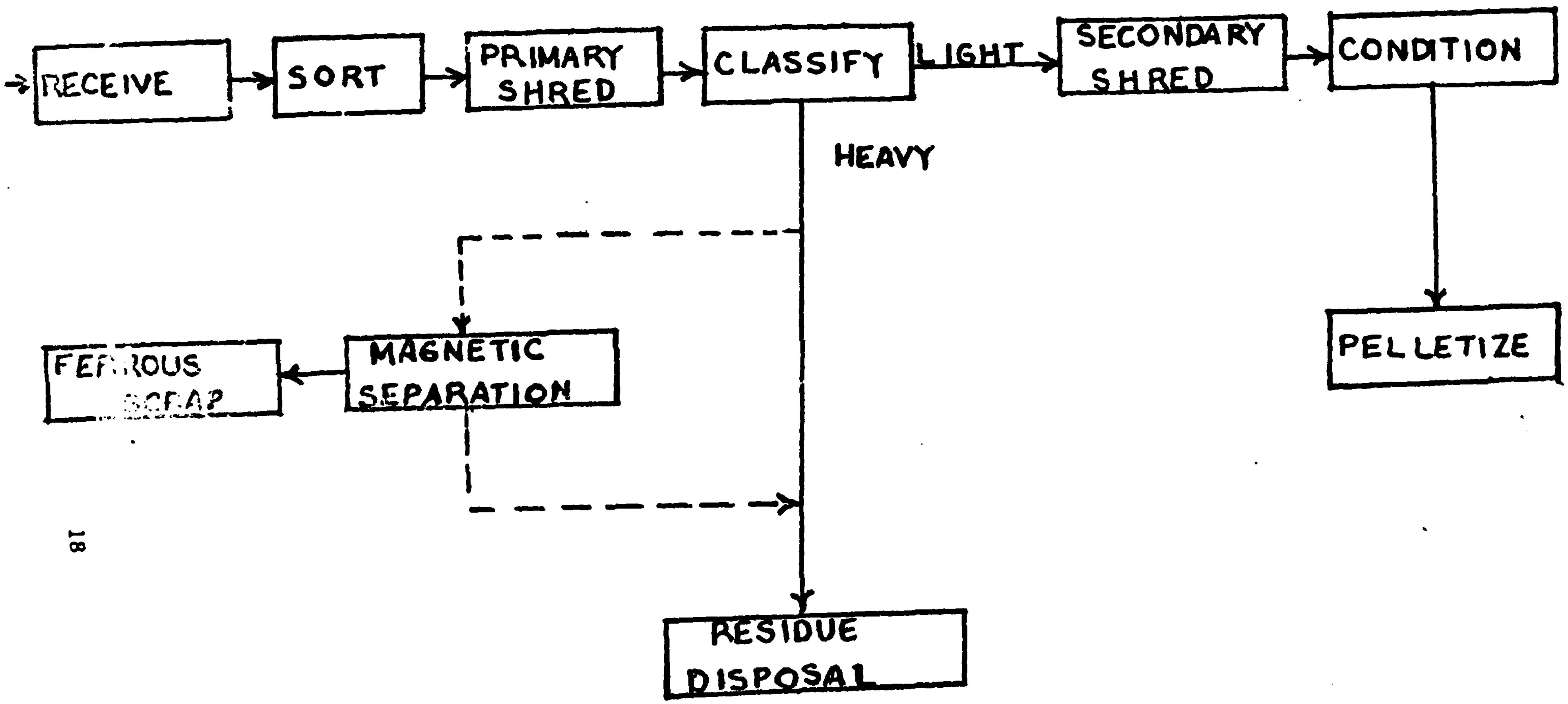


FIGURE 2 DENSIFIED RDF PROCESSING SYSTEM (10)



PREPARATION OF RDF

It has already been stated that the heating value of Navy solid waste is approximately 6300 Btu/lb. If the moisture content could be reduced from 27% to 20%, the heating value would theoretically increase to 7000 Btu/lb if all other variables remain constant. This is approximately a 16% increase in the heating value. A decrease in moisture content from 27% to 10% increases the heating value to 8000 Btu/lb, a 27% increase. In other words, as shown by equation (1), for every percent decrease in moisture content the heating value is increased by 100 Btu/lb. The same is true for a 1 percent decrease in ash content.

Figure 3 provides a mass and energy balance per ton of input to an incinerator for MSW with a moisture content at 27%, a heating value of 5050 Btu/lb and all metal and glass has been removed. The heat loss is 15% or 1,515,000 Btu with 100% excess air. If moisture content is reduced from 27% to 20% the heating value increases from 5050 Btu/lb to 5750 Btu/lb. The loss from the incinerator is still 15% or approximately 1,725,000 Btu. Based on the mass balance, 12.58 lb dry air/lb organics is required to incinerate the refuse (9). There is approximately 0.0-43 lb H_2O per pound of dry air at ambient conditions (8). When moisture content decreases to 20%, the weight percent of organics increases to 70% or approximately to 1400 lb per ton of refuse. Which raises the heat available to 11,500,000 Btu/ton. The air requirement increases to 17,620 lb dry air per ton of refuse and this air has approximately 77 lb of water vapor associated with it. The total evaporation losses increase by 4.9% from 8,569,109 Btu to 8, 986,781 Btu due the increased air requirement. There is, however, an overall net gain when compared to a moisture content of 27%. The net available energy improves from 15,892 Btu/ton at 27% moisture content to 788,220 Btu/ton at 20% moisture content.

Not all reductions in moisture content can provide such drastic results. Figure 4 illustrates as moisture content decreases the available heat increases but at a decreasing rate. The assumption is made that all other variables remain constant, i.e. the ash content remains at 200 lb per ton of refuse. In reality, the ash content would probably increase but not significantly enough to change the incinerator performance.

In order to reduce the moisture content of refuse, the source of the moisture must be determined. Table 12 lists the different components of refuse and how much they contribute to the moisture and ash content. By far the major portion of the moisture is found in food and yard waste while the major source of ash is metal and glass. As was shown in Table 7, 26% of the solid waste generated by the Navy is food or yard waste. If these could be eliminated, the moisture content would decrease from 27% to approximately 10% and as shown in Figure 4, the net heat available would theoretically be 1.72 MBtu/ton of refuse.

TABLE 12 MOISTURE AND ASH CONTENT OF REFUSE (16)

	% Moisture "AS DISCARDED"	lb Moisture / 100 lb Dry Refuse	lb Ash / 100 lb Dry Refuse
Metal	2.0	0.22	10.13
Paper	8.0	3.97	2.74
Plastics	2.0	0.03	0.17
Leather and Rubber	2.0	0.04	0.24
Textiles	10.0	0.27	0.08
Wood	15.0	0.52	0.09
Food Waste	70.0	23.10	2.17
Yard Waste	50.0	10.79	0.54
Glass	2.0	0.23	11.21
Miscellaneous	2.0	0.05	1.62

In a practical sense total elimination of the food and yard waste may not be possible, but in a Navy community a 50% reduction is by no means

impossible and may even be conservative. If waste from Navy galleys was separated into garbage and dry waste and then individually collected, the volume of food waste in the RDF and moisture content of the refuse would be significantly reduced. If housing occupants were encouraged to utilize garbage disposals instead of discarding the garbage into receptacles, a change in food waste would also be observed. If yard waste was to be collected only in trash bags and only on given days, the major portion of the yard waste would be eliminated. These ideas are simple, practical and would show results. Even if complete evaporation could not be achieved, a 50% cooperation rate could show significant results.

Moisture contents is not the only concern with RDF, however, ash is also important. The higher the ash content the greater the disposal cost. Metal and glass are the major sources of ash in refuse (Table 12) and generate other problems as well. Metals cause slagging in incinerators. The more slagging that takes place results in more maintenance and thus higher operating costs. Glass has a low melting point and as such causes what is termed clinkering (8). The ash particles cling together and when the glass cools a tight adhering layer can be formed in the bottom of the incinerator. The removal of this layer can be difficult and again results in increased maintenance cost. Even if the glass is maintained in a molten state the ash particles will cling together and make ash removal more difficult.

The elimination of metal and glass in refuse would be even easier than eliminating food and yard waste. Separate receptacles could again be provided for glass and metal refuse and because the possibility of protrusive odors is minimal collection frequency could be greatly reduced. There is also the possible redemption of recyclible metals. Even if the quantity is not large enough to warrant the Naval station collecting and redeeming these

metals, there are always organizations willing to do the collecting of metal containers if they can keep the funds received upon redemption.

It has also been recorded that there are a number of significant benefits to burning shredded refuse rather than unshredded refuse; these benefits include better surface area-to-volume ratios, simpler ash handling equipment, and elimination of hot spots through better refuse mixing (3). Therefore, if the Navy is going to utilize raw refuse as a fuel, some degree of presorting is required to decrease the moisture content and ash content as well as removing metal and glass constituents. This presorting can be accomplished prior to or after arriving at the incineration sight. Once the refuse has been presorted it should be shredded to improve handling and thermal characteristics.

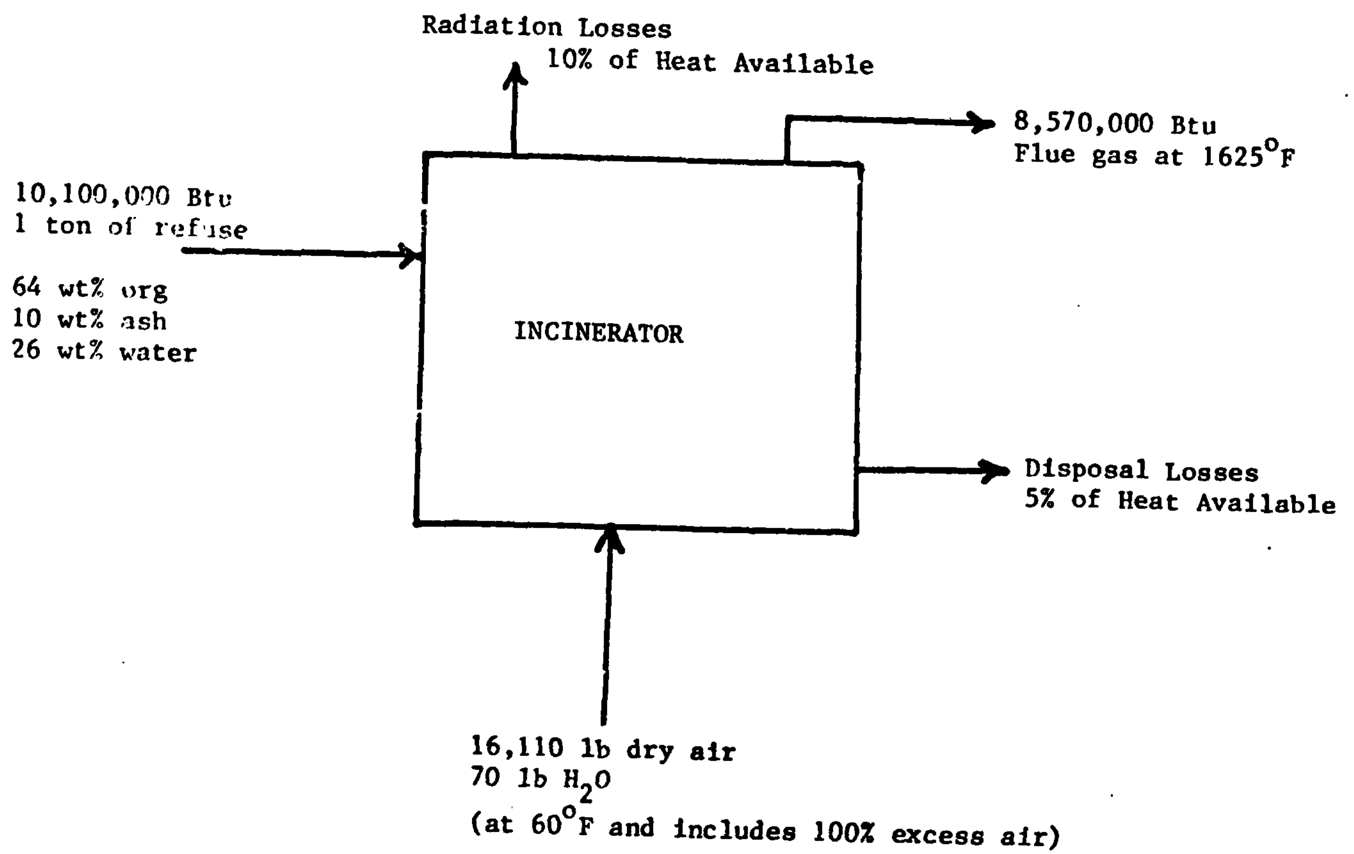


FIGURE 3 INCINERATOR MASS AND ENERGY BALANCE

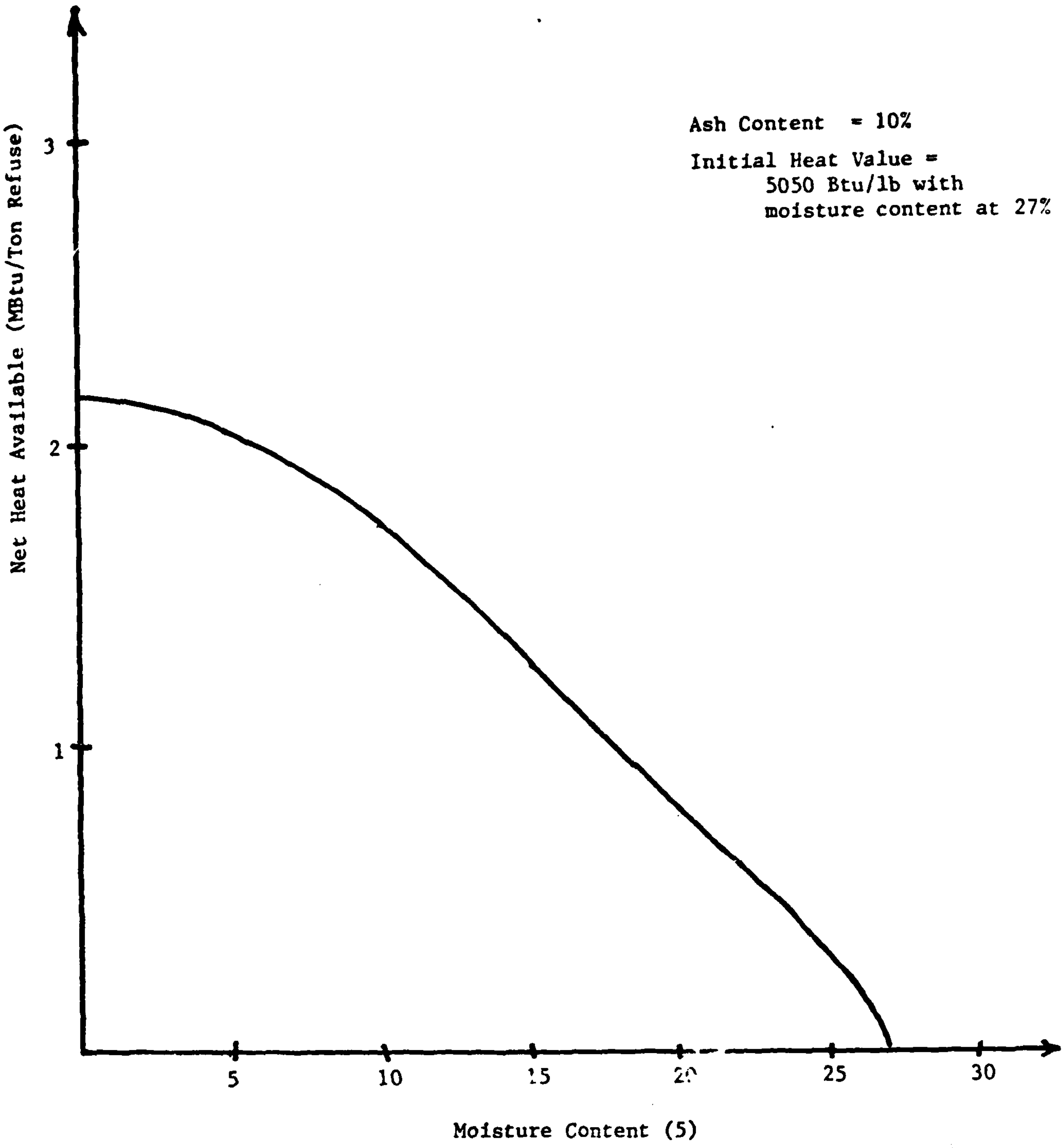


FIGURE 4 MOISTURE CONTENT vs NET HEAT AVAILABLE

ENVIRONMENTAL CONSIDERATIONS

Anytime a solid fuel is used to generate heat there is both air emissions and solid waste (ash) that must be monitored and disposed of safely. This means that there should be no detrimental effect on the environment. The emphasis placed on environmental protection has greatly increased over the last two decades and rightfully so. Table 13 gives an indication of this trend. As shown, the first federal standards for particulate matter exiting the stack of an incinerator burning refuse was established by HEW in 1966 where by they allowed 3.76 lbs. of particulate matter to be emitted per ton of refuse charged to the incinerator.

TABLE 13 TIGHTENING OF PARTICULATE EMISSION STANDARDS (1)

		lbs/100 lbs flue gas at 50% excess air	gr/scf at 50% excess air	gr/scf at 12% CO_2	lbs/ton of refuse charged
1960	ASME	0.850[a]	0.442	0.497	9.58
1966	Federal HEW	0.342	0.178	0.200[a]	3.77
1971	Federal EPA	0.362	0.188	0.212	4.00[a]
1971	Federal EPA	0.272	0.089	0.100[a]	1.88
1971	Federal EPA	0.136	0.071	0.080[a]	1.50

[a]Standard given in code.

This was lowered to 1.88 lbs. and then to 1.50 lbs. per ton of refuse by the EPA in 1971, which is a 60 percent decrease within a five year time frame. It was during this period in history that standards became the rule rather than the exception.

With incineration, there are five factors that are the major determinants of the amount of particulate or fly ash that results from the combustion of refuse. These factors are: refuse composition, completeness of combustion,

burning rate, the grate system utilized in the incinerator, and the underfire air rate (1). These parameters also affect the discharge of other noxious gases as well as particulate matter. The gases of major concern are carbon monoxide (CO), the nitrogen oxides (NOx), and sulfur oxides (SOx). Carbon monoxide is both toxic and combustible and is a product of incomplete combustion. The nitrogen oxides form nitric acid and sulfur oxides form sulfuric acid and the amounts of both are a function of composition and air flow into the system as well as operating temperature. The formation of hydrochloric acid is also possible when refuse is incinerated and is a function of the initial composition. Also, if refuse is heated under starved air conditions, organic acids can be formed, most of which are burned above the fuel bed (3).

Several air particulate control systems have been and are being utilized in an attempt to control air particulate emissions. Table 14 provides a listing of these systems and the corresponding efficiencies. As can be seen, the type of system selected depends on composition of the flue gas and correspondingly what must be removed. Electrostatic precipitators and fabric filters produce high efficiencies for the removal of fine particulate matter and volatile metals but have little effect on the oxides, bydrocarbons, or bydrogen chloride. Wet scrubbers produce high removal efficiencies for coarse particulate matter and volatile metals, and they are also effective in removing the oxides, hydrogen chloride, and polynuclear hydrocarbons.

The selection of air particulate removal systems is a function of the flue gas composition. There are several properties that govern how well a particular system will perform. If there is a large quantity of particulate matter in the flue gas, an electrostatic precipitator may not be desirable, even though it

TABLE 14

AVERAGE CONTROL EFFICIENCY OF APC SYSTEMS - APC SYSTEM REMOVAL EFFICIENCY (WEIGHT PERCENT) (3)

APC Type	Mineral Particulate	Combustible Particulate[a]	Carbon Monoxide	Nitrogen Oxides	Hydro-carbons	Sulfer Oxides	Hydrogen Chloride	Polynuclear Hydro-carbons[b]	Volat Metal
None (Flue Setting Only)	20	2	0	0	0	0	0	10	2
Dry Expansion Chamber	20	2	0	0	0	0	0	10	0
Wet Bottom Expansion Chamber	33	4	0	7	0	0	10	22	4
Spray Chamber	40	5	0	25	0	0.1	40	40	5
Wetted Wall Chamber	35	7	0	25	0	0.1	40	40	7
Wetted, Close-Spaced Baffles	50	10	0	30	0	0.5	50	85	10
Mechanical Cyclone (dry)	70	30	0	0	0	0	0	35	0
Medium-Energy Wet Scrubber	90	80	0	65	0	1.5	95	95	80
Electrostatic Precipitator	99	90	0	0	0	0	0	60	90
Fabric Filter	99.9	99	0	0	0	0	0	67	99

[a]Assumed primarily $<$ 5 microns.

[b]Assumed two-thirds condensed on particulate, one-third as vapor.

[c]Assumed primarily a fune $<$ 5 microns.

has the best removal efficiency, because it cannot handle the volume required. It the particles are relatively large, a cyclone separator may be more effective. A wet scrubber may not perform satisfactorily if the specific gravity of the substance being removed is not in the right range. If the particles are electrically neutral, an electrostatic precipitator may not be desirable. If the flue gas contains a large quantity of oxides, then the wet scrubber would be the most effective system because oxides are relatively soluble in water. When selecting an air particulate control system, the quantity of air being processed, the particle size distribution, the specific gravity, the electrical characteristics, and the chemical composition are all important properties and should be evaluated (3).

Once the particulate matter in the flue gas (fly ash) has been collected, it must be disposed of by some means. Typically this is accomplished by disposal at a landfill sight. As such, the leachate from this ash could create toxicity problems. During a test and evaluation of the heat recovery incinerator system at Naval Station, Mayport, Florida, the removal efficiency of a cyclone dust collector and the toxicity of the fly ash leachate were evaluated. It was noted that 95 percent of the fly ash collected was greater than 46 um in size. The reason being that multi-clones are not efficient particle-collecting devices when particle sizes are below 20 to 30 um. Incinerator particulates are generally smaller than this and as such a cyclone dust collector is not an efficient means of removing particulate matter generated by incinerator operation (7).

The cyclone ash leachate was also tested for toxicity and the results are shown in Table 15. Cadmium and lead concentrations were above the prescribed

standards. The cadmium concentration limit was exceeded by 135% and the lead concentration exceeded the limit by 64%. This means that the fly ash would have to be mixed with some other material before disposal, in an effort to reduce the concentration levels by dillution (7).

TABLE 15 CYCLONE ASH LEACHATE TOXICITY RESULTS (7)

Contaminant	Fly ash (cyclone) (mg/ℓ)	Maximum allowable* (mg/ℓ)
Arsenic	0.058	5.0
Barium	0.775	100.0
Cadmium	2.35	1.0
Chromium	0.590	5.0
Lead	8.195	5.0
Mercury	0.0016	0.2
Selenium	0.018	1.0
Silver	0.105	5.0
Endrin	< 0.005	0.02
Lindane	< 0.001	0.4
Methoxychlor	< 0.010	10.0
Toxaphene	< 0.010	0.5
2, 4-D	< 0.002	10.0
2, 4, 5-TP	< 0.002	1.0

* As specified in 40 CFR 261.24.

Based on the results of this test it is apparent that cyclone dust collectors do not provide adequate particulate removal and the material removed can form a toxic leachate. Therefore another type of air particulate control should be utilized.

A similar test was conducted for the Air Force on a stoker hot water generator that was fueled by dRDF. The boiler that was tested was located in Building 1240 Heating Facility of Wright-Patterson Air Force Base, Ohio. This generator had been previously fueled by coal. Table 16 shows the stack emissions for both dRDF and coal with an electrostatic precipitator installed. Note that there is no appreciable difference in emissions and in neither case were the maximum permissable limits exceeded (17).

TABLE 16 STACK EMISSIONS ($lb/10^6 Btu$) (17)

	dRDF	Coal	Maximum permissable*
Particulate			
ESP inlet	.925	.933	--
ESP outlet	.019	.023	.10
HC	.04	.04	--
CO	.22	.24	--
SO_x	.38	.80	1.2
NO_x	.45	.66	.70
Carbonyls	.005	+	--
Formaldehyde	N.D.!	N.D.	--

* 40 CFR 60.

\+ Not tested

! None detected above the detection limit of 1×10^{-6} g/sec.

Precipitator performance is usually analyzed through the use of the Deutch Equation which is expressed as follows:

$$W = \frac{Q}{A} \log_e \frac{1}{P}$$

W = drift velocity (ft/min),
Q = volumetric flow rate (ACFM),
A = electrode plate area (ft^2),
P = $\frac{\text{outlet particulate rate}}{\text{inlet particulate rate}}$

Drift velocity is a measure of how effectively a precipitator causes particles to migrate toward the collector plates (perpendicular to the gas flow). The precipitator removal efficiencies were greater than 98% for both coal and dRDF, but the drift velocity was somewhat less for dRDF. As a result, the dRDF required more precipitator power but a slightly

higher removal efficiency was obtained. (17)

In this particular test the fly ash leachate was not analyzed for toxicity. It was noted, however, that there was no measurable increase in stack emissions of lead or cadmium when dRDF was used compared to coal. Since lead and cadmium emissions are usually associated with RDF combustion, it can be assumed that an electrostatic precipitor is effective in removing these pollutants and that they would be present in relatively high concentrations in the fly ash. So again, the fly ash should be mixed with some other material before disposal.

Even though fly ash can create a possible disposal problem, the electrostatic precipitator does provide the necessary particulate removal efficiency when RDF is utilized in a heat recovery system. More research, however, should be conducted to determine an adequate means of disposal of the fly ash.

Not only must fly ash that is entrained in the flue gas be disposed of separately, but the unburned residue of RDF known as bottom ash is also a potential source of pollutants. In the Mayport, Florida test, bottom ash leachate was also analyzed for toxicity. Table 17 gives the results of this analysis. It should be noted that none of the maximum allowable limits were exceeded. The cadmium concentration was well below the maximum allowable limit. The lead concentration, however, was within 17% of the upper limit. Therefore if the original composition of a refuse is significantly different thatn that tested, there is the possiblity of exceeding the maximum allowed lead concentration.

Air particulate emmissions and ash leachates are not the only sources of pollution, there is a large quantity of dust created in and around RDF handling equipment. Enough dust has been experienced to create

a discomfort hazard to the operators. In one report it was suggested that dust control systems be installed on refuse handling systems particularly at transition points (18).

TABLE 17 BOTTOM ASH LEACHATE TOXICITY RESULTS (7)

Contaminant	Bottom ash (mg/ℓ)	Maximum allowable* (mg/ℓ)
Arsenic	0.122	5.0
Barium	1.60	100.0
Cadmium	0.135	1.0
Lead	4.170	5.0
Mercury	0.0025	0.2
Selenium	0.020	1.0
Silver	0.085	5.0
Endrin	< 0.005	0.02
Lindane	< 0.001	0.4
Methoxychlor	< 0.010	10.0
Toxaphene	< 0.010	0.5
2, 4-D	< 0.002	10.0
2, 4, 5-TP	< 0.002	1.0

*As specified in 40 CFR 261.24.

Based on the Mayport, Florida and Wright-Patterson Air Force Base tests, it is possible to operate RDF fueled heat recovery systems and meet the present air emmission standards. A fly ash was produced, however, which resulted in a leachate containing cadmium and lead in concentrations exceeding the prescribed limits. Bottom ash leachate concentrations were all within specified limits and as such bottom ash was not considered a hazardous waste. Dust collectors have also been strongly recommended for RDF transport systems.

ECONOMIC ANALYSIS

In September, 1980, the Naval Civil Engineering Laboratory (NCEL) Environmental Protection Division, Port Hueneme, California, contracted with SCS Engineers, Long Beach, California, to prepare a document on the application of resource recovery technology. This document contains fuel characteristics, system specifications, product market potentials, and cost estimates for both fuel recovery and combustion systems. This information was used extensively in performing an economic analysis on a heat recovery system utilizing raw (unprocessed) solid waste as a fuel (10).

This document stated that the price of solid waste fuel is a function of; displaced fuel cost and availability; RDF quality, quantity, and deliverability (guaranteed/non-guaranteed); future conventional and alternate fuel price trends; technical compatibility of combustion equipment; air pollution control requirements; and residue disposal requirements.

Figure 5 shows the operating and capital costs associated with the transfer and transportation of solid waste. Only one or two operators are required for a system designed to process up to 100 TPD. Since labor is a major portion of the operating costs, these costs are assumed to be constant and equal to approximately $25,000 for plants smaller than 100 TPD. The lower end of the capital cost curve is linear with an approximate slope of $50/TPD from 0 TPD to 200 TPD. Therefore the capital cost of a 10 TPD plant is relatively insignificant with a value of about $500.

Figure 6 is a graphical depiction of the operating and maintenance cost and the capital cost of a modular incineration heat recovery system designed to burn raw refuse. Based on limited data, the operating and maintenance costs are linear with a slope of $4000/TPD. A more realistic

curve, however, shows that there is some economy to scale. This results because again labor is a major operating cost and as a plant is enlarged more operators are not necessarily required. The lower curve will be used in this analysis. Therefore a 10 TPD plant has an operating and maintenance cost of $40,000. The capital cost curve is linear with a $25,000/TPD slope and the capital cost of a 10 TPD plant is $250,000. A breakdown of each individual cost was not provided but a breakdown of cost estimate for other systems was provided. In these estimates labor costs were estimated at $20,800/man year and air pollution control equipment was included in the capital investment calculations.

Total capital investment for both the recovery system and the combustion system must be annualized and added to operating and maintenance cost to arrive at a total annual cost. A 10% discount factor and a 15 year expected life was used for this calculation. For a 10 TPD plant the total capital investment is $250,500 with an annualized cost of $32,940/yr. Since the operating and maintenance cost for this plant is estimated to be $65,000/yr, the total annualized cost would be $97,940/yr. Figure 7 shows the calculated annualized costs for plants up to 80TPD.

It has been estimated that on the average 3,700 lbm of steam per ton of refuse can be produced (10). This steam is in the range of 100 to 280 psig and therefore would have an average enthalpy of 1196.14 Btu/lbm (19). This means that 4.426 MBtu of steam per ton of refuse can be generated. Thus a 10 TPD plant operating 365 days per year can produce 1.62×10^4 MBtu/yr. This relates to a production cost of $6.06/MBtu. Figure 8 depicts the steam production costs of various sized platns. As is illustrated, there is a definite economy to scale.

Electricity production is limited to between 30 KWH/ton to 100 KWH/ton. Figure 9 is a graphical presentation of electricity production costs. The upper curve shows the production costs if generation rate is limited to 30 KWH/ton and the lower curve for a generation rate of 100 KWH/ton. At the lower generation rates there is a slight economy of scale; for a 10 TPD plant the production cost is about $0.78/KWH and for an 80 TPD system the cost is approximately $0,65/KWH. This corresponds to a 17% reduction in generation costs. At 100 KWH/ton, however, the generation costs are relatively constant with an average cost of $0.21/KWH.

Table B-2 lists the price that Navy Public Work Centers have to pay for their steam whether it is generated in house or purchased. The average price for FY81 was $8.39/MBtu. Appendix A contains questionaires from which this data was extracted. These questionaires also show that in some cases a 10% growth in steam requirement is expected and some of the operating boilers have already exceeded their projected economic life. With steam requirements increasing and boilers needing replacement, modular incinerators are an option that should be considered. It is projected that these incinerators can produce steam for $2.00/MBtu less than present methods.

Modular incinerators are not as attractive for electricity production because costs are an order of magnitude higher than is presently being paid (Appendix A, Table B-2).

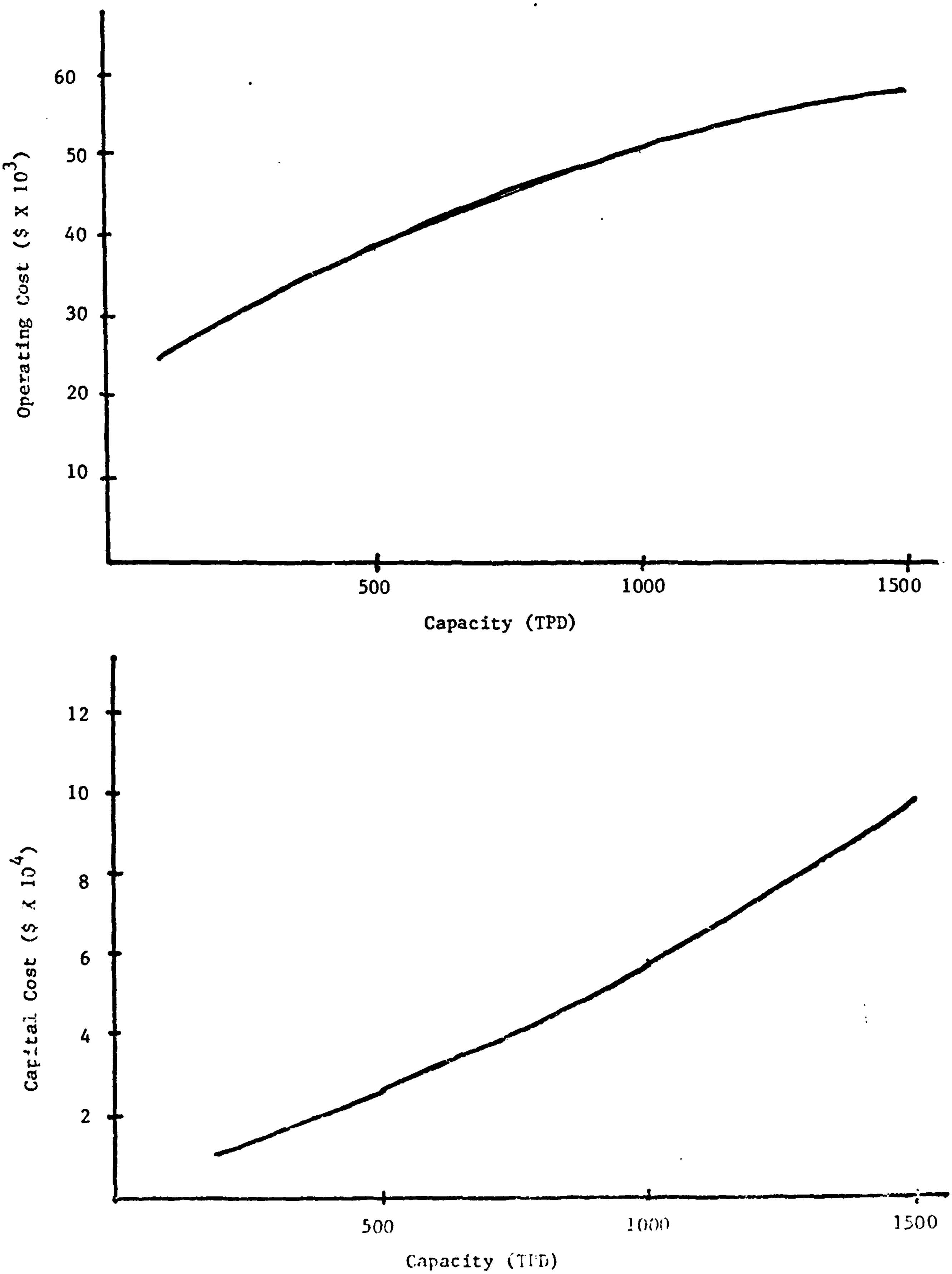
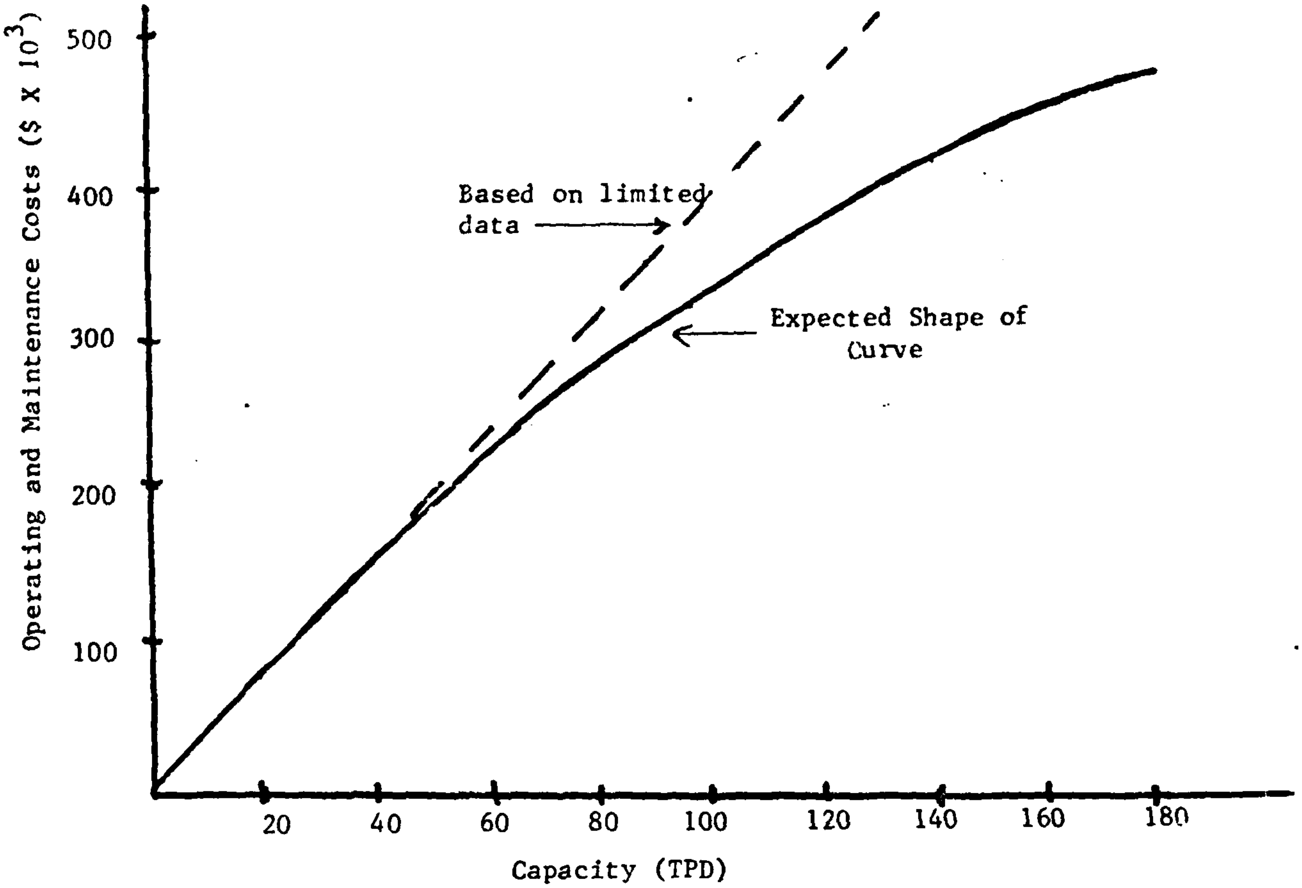


Figure 5 Solid Waste Transfer and Transportation Cost (10)



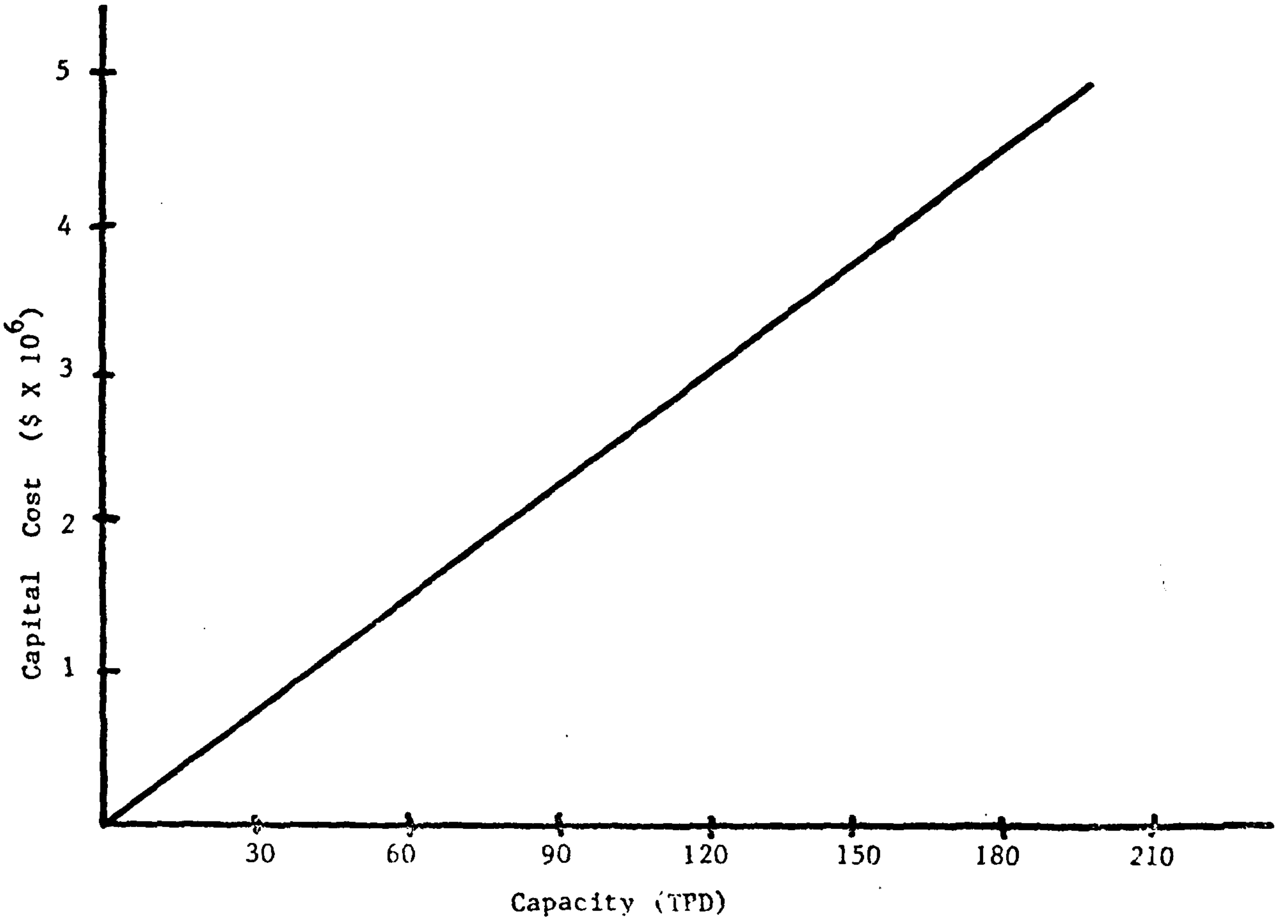


Figure 6 Modular Incinerator Costs (10)

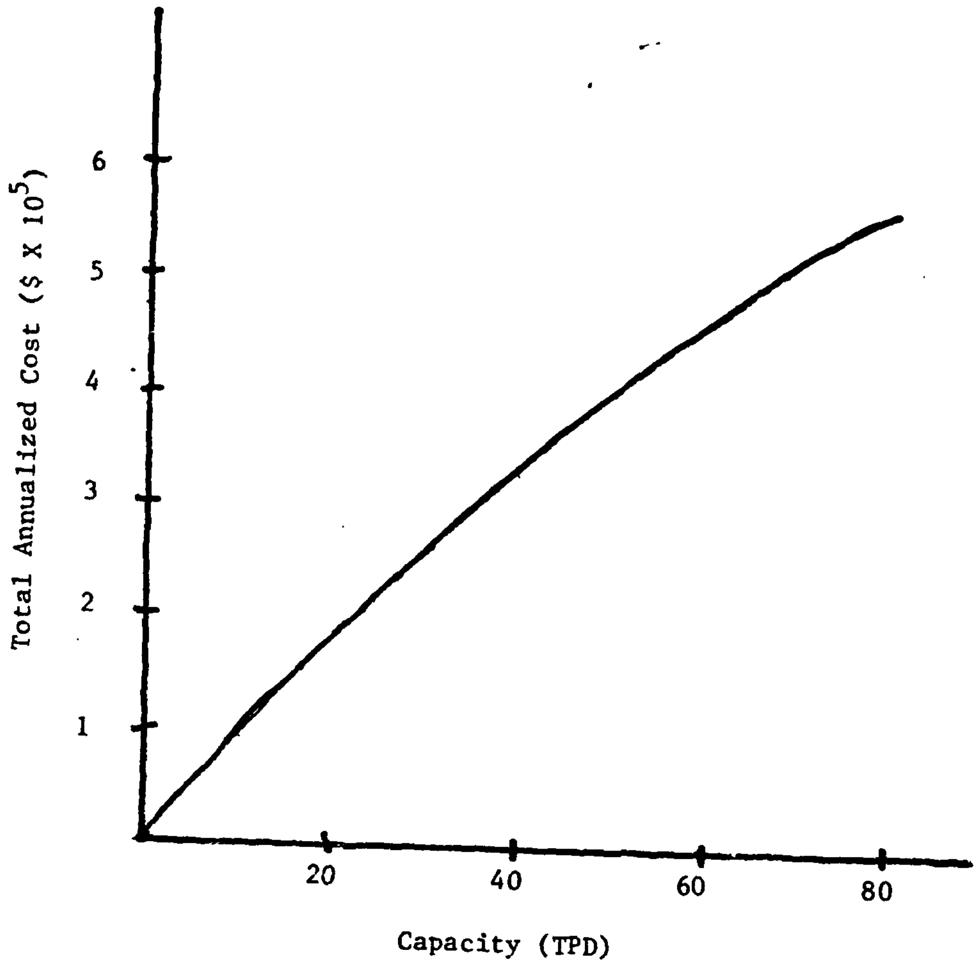


Figure 7 Total Annualized Cost

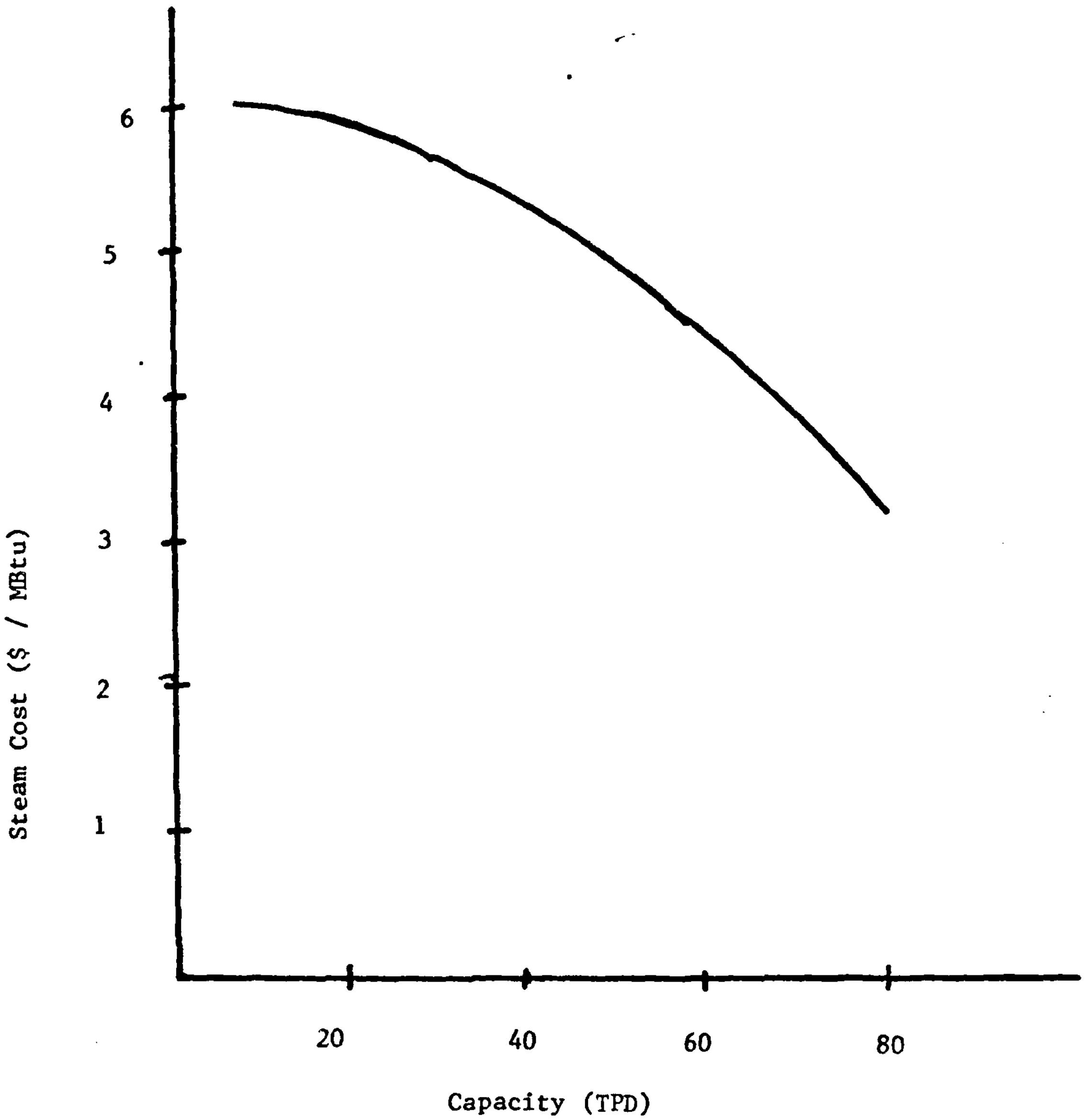


Figure 8 Steam Production Cost

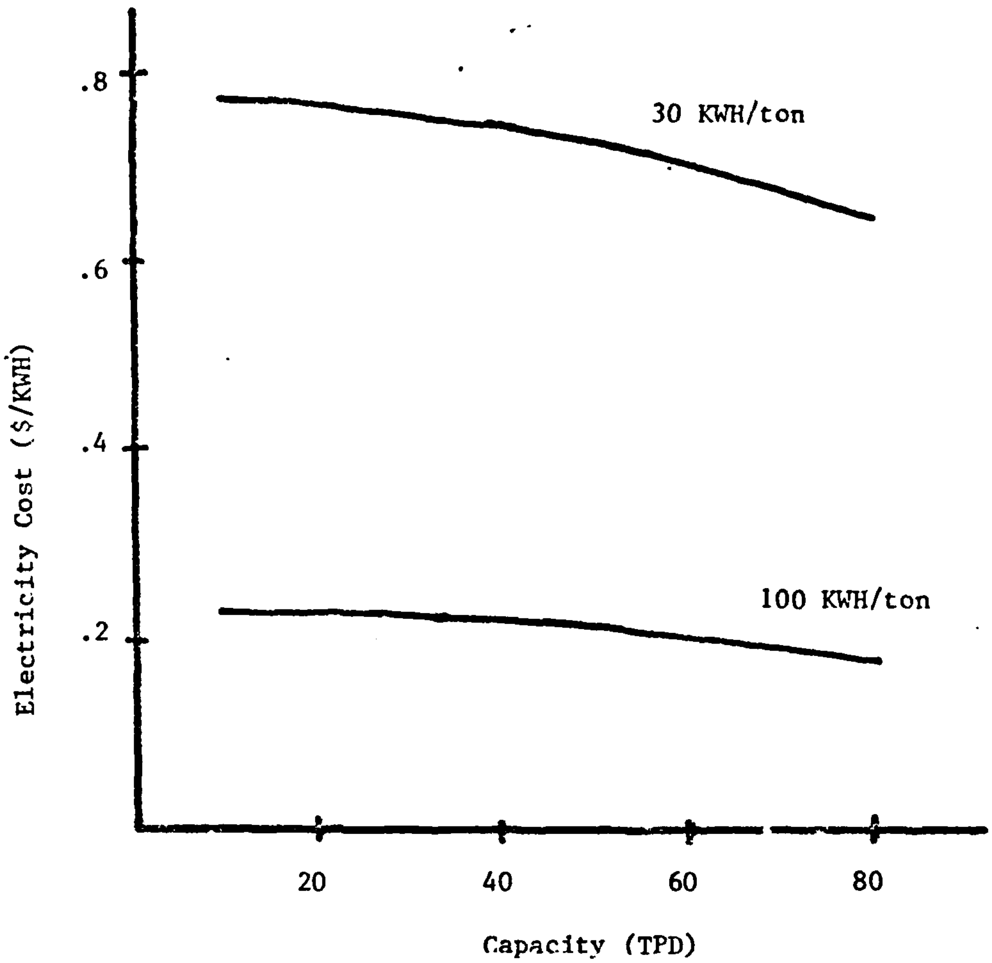


Figure 9 Electricity Production Cost

UTILIZATION BY THE NAVY

The first steam generating water-wall furnace to be built in the U.S. Navy for the incineration of solid waste is at the Norfolk Naval Station, Norfolk, Virginia. Design of the plant was completed in 1965 by Metcalf and Eddy engineers and the construction of the plant was completed by the Van-Guard Corporation of Norfolk, Virginia, in May 1967. The plant consists of two 180 ton/day incinerator furnaces and each furnace can produce 50,000 lbm/hr of 275 psig steam. The plant receives refuse collected from Naval activities and ships in the area and accepts a limited refuse load from the neighboring cities of Norfolk, Little Creek, and Fort Storey. Cyclone separators were originally used as a fly ash removal system. In 1976, the separators were replaced with two electrostatic precipitators. The average gross processing cost is $29.63/ton. It was estimated that to replace the facility would cost about $16,000,000 as compared to a total investment of $4,310,000 from 1967 to 1979 (20).

Another Navy plant was built in 1977 at Portsmouth Energy Recovery Facility, Portsmouth, Virginia. The plant was designed by the Day and Zimmerman Co. and consists of two 80 TPD water-wall incinerator furnaces. The two incinerator boilers are designed to produce 30,000 lbm/hr of steam each at 125 psig. The total cost of the plant was $4,200,000. In 1980 the operating and maintenance cost totaled $330,000 (20).

The last two heat recovery incinerators (HRI) built for the Navy are located at Naval Station, Mayport, Florida and Naval Air Station, Jacksonville, Florida. The Mayport HRI is a field-erected, refractory lined incinerator designed to burn unprocessed Navy base waste. The Jacksonville HRI is a

packaged incinerator with proprocessing to remove glass and metals. Both plants are designed to process 40 - 50 TPD (7).

The Mayport, FLorida HRI was tested and evaluated in 1981. During this test, stack emissions were monitored and found to be within acceptable limits utilizing cyclone separators for particulate control. It should be noted, however, that only visible emission standards are in effect for incinerators processing less than 50 ton/day in the state of Florida. If this system were subject to the mass emissions limit of 0.08 grain/scf (corrected to 12% CO_2) for systems larger than 50 TPD, a different air particulate control system would have to be installed because the average particulate concentration being discharged is 0.669 gr/scf (corrected to 12% CO_2) (7,9).

If the Navy is to continue utilizing HRI's, they must prove to be economically feasible. It can be seen in Figure 6 that there is little economy of scale at the lower refuse processing rates. Many of the studies conducted for the Navy have indicated that processing solid waste into fuel and using this fuel in boiler plants is uneconomical (9). This report shows, however, that it is possible to produce steam at a lower cost than present conventional methods when raw refuse is used as the fuel in a new HRI system. (See Appendix A and Table B-2).

There are several things to consider, however, before a rational decision as to applicability of HRI systems can be made. One of the things to consider is whether the steam demand is large enough to warrant such a system. The demand must be large enough and centralized enough to utilize the steam being produced. A base may have an overall steam demand such that on paper a HRI appears to be economically feasible, but this same steam utilization system may be so wide spread and disjointed that no one user can utilize the steam that a small system can generate. Table 18 illustrates such a

phenomenom. The steam demand for Public Works Center (PWC) Subic Bay, Philippines, appears to be able to support two 80 TPD plants. This, however is not the case. This PWC supports four bases and the demand is spread out to different barracks, galleys, docks, and other facilities on these bases. Most of the buildings are supported by separate individual boilers with the only demand being large enough to support even a 10 TPD to 20 TPD plant is for the ships tying up to the dock.

TABLE 18 STEAM PRODUCTION POTENTIAL

Plant Size	Steam Production lbm X 10^6	Potential MBtu X 10^3
10 TPD	13.5	16.15
20 TPD	27	32.3
40 TPD	54	64.6
60 TPD	81	96.9
80 TPD	108	129.2

Public Works Center (PWC)	Steam Requirements for FY 81 lbm X 10^6	MBtu X 10^3
Pennsacola, Fla.	2.14	2.55
San Francisco, Ca.	685.9	816
San Diego, Ca.	155.5	185.85
Guam	67.3	80.4
Subic Bay, Philippines	199.3	237.4
Pearl Harbor, Hi.	165	196.9

Another consideration is the availability of a HRI system. Figure 11 illustrates how payback period varies with downtime. As shown the payback period based on replacement of existing systems increases in the range of 24% to 300% when downtime increases from 10% to 20%. So if the system is not available at a reasonable level the transition would not be practical. In order to determine the availability of HRI systems, the Navy contracted with VSE Corporation of Oxnard, California, to conduct a reliability, maintainability, and availability evaluation of the Mayport

heat recovery incinerator program. Based on data collected from 29 September 1980, to 28 September 1981, there is a 0.4890 probability that the HRI will be capable of performing all of its functions when called upon at any random point in time. The reliability evaluation showed that there is a 0.3858 probability that the HRI will operate trouble-free for 120 consecutive hours during anormal operation cycle (21).

The maintainability index (MI) was not any better. The MI for the HRI installation was 1.12. This means that for every twenty-four hours of operation, twenty-seven hours are spent on corrective and preventive maintenance. The major source of failures requiring corrective maintenance were the feed ram sticking, crane radio electronics failing, and ash conveyor problems (21). Even though the above results are not very favorable it should be kept in mind that this system is a relatively new system and that a lot of the present maintenance problems will not be prevalent once operational experience is obtained. For example, three repairs that required 622 manhours were associated with design changes. Also, during corrective maintenance and HRI idle periods, considerable amounts of preventive maintenance were performed, but not necessarily required. Taking these items into account drops the MI to 0.41 which means that for every twenty-four hours of operation, ten man-hours of corrective and preventive maintenance is required (21).

The overall HRI system evaluation showed a thermal efficiency of 0.415, specific total manhours of 0.497 manhours/MBtu, the average cost of steam was $9.13/MBtu, and a percent landfill reduction of 70% (21). This corresponds to approximately 48% downtime when compared to production cost based on operating 365 days per year, and 24 hours per day as

calculated in this report. The cost is also higher than present systems.

With reliability being rather low, backup systems must also be maintained. The maintenance cost for these backup systems depends on the level of reliability required, but must be taken into account when conducting an economic feasibility study of a HRI system.

A major consideration is the ability to meet environmental standards. As Table 19 illustrates, the specific standards depends on plant location. Each state has its own emission standards and there are Federal standards as well. It is vitally important that one evaluate the system being contemplated to insure that all emissions are within specified limits. If there is a comflict between state and Federal regulations, the most restrictive should govern.

TABLE 19

SUMMARY OF SELECTED REFUSE INCINERATOR EMISSION STANDARDS (9)

Area	Capacity of Incinerator	Visible Emissions	Mass Emissions
Puget Sound Area of Washington	All	Less than Ringelmann #1 (20% density); for 57 min/hr 3 min/hr (no limit)	0.10 grain/scf (corrected to 12% CO_2 exclusive of CO_2 from auxilary fuel)
City of Philadelphia, PA	All	Less than 30% density on Ringleman scale for 59.5 min/hr; 30 sec/hr or 3 min/day less than 60% density	0.08 grain/scf (corrected to 12% CO_2)
State of Florida	50 ton/day	Zero visible emissions except for 3 min/hr when emissions are not to exceed 20% density on Ringlemann scale	
	50 ton/day		0.08 grain/scf (corrected to 12% CO_2)
San Francisco Bay Area in California	50 ton/day	Less than Ringlemann #1 (20% density) for 57 min/day 3 min/hr (no limit)	0.15 grain/scf (corrected to 6% O_2 with no auxilary fuel)
(Comparable to standards in Los Angeles area)	50 ton/day		0.08 grain/scf (corrected to 12% CO_2)
New Hampshire	200 lb/hr	--	0.2 grain/scf (corrected to 12% CO_2)
	50 ton/day	--	0.08 grain/scf (corrected to 12% CO_2)
Hawaii	50 ton/day	--	--
	50 ton/day	--	0.08 grain/scf (corrected to 12% CO_2)

*Dry gas basis in all cases.

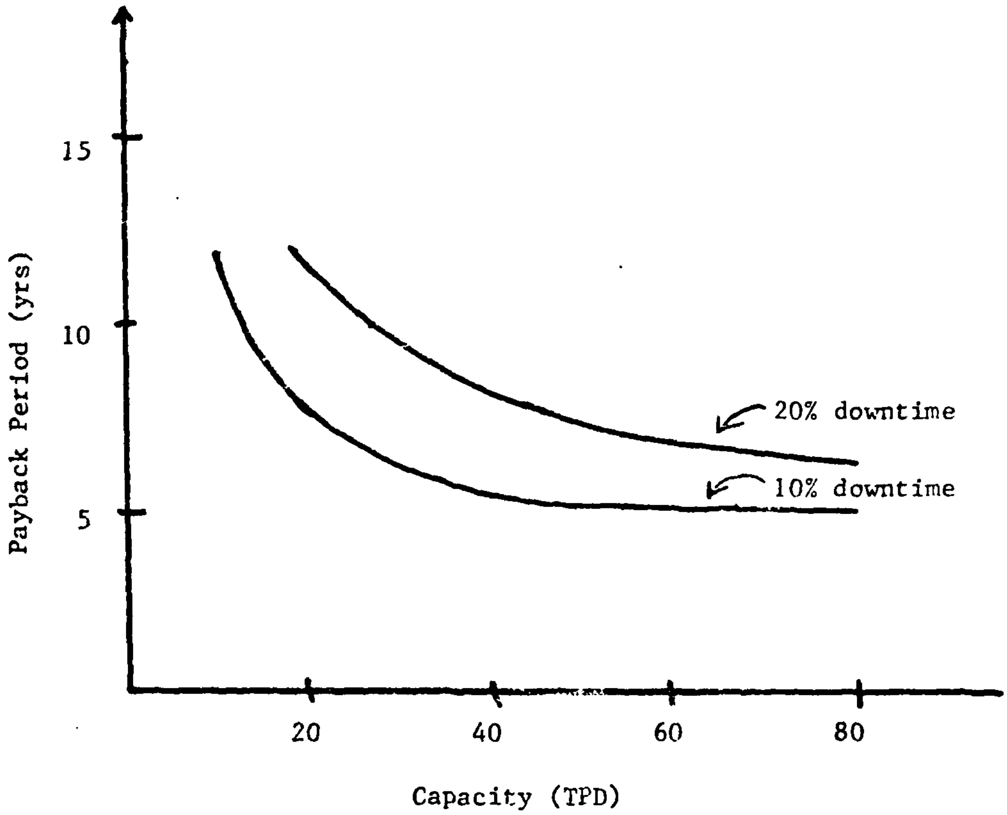


Figure 10 Payback Period

CONCLUSIONS AND RECOMMENDATIONS

Waste is continuing to be generated at a rate of approximately 3.0 lb/person/day. This relates to less than 20 TPD for the majority of Naval bases. Landfill is the most common method utilized by the Navy for disposal of this waste. Landfill operators are being required to meet tighter restrictions as a result of the Resource Conservation and Recovery Act (RCRA) and the Safe Drinking Water Act. Land area is also becoming more scarce and thus less available for utilization as a landfill. Present landfill capacity is being slowly consumed to the point that it has been estimated that 45% of all sites utilized by the Navy must be expanded or replaced within 7 years. Therefore a decision must be made as to future solid waste disposal methods. Thsi decision should be made well in advance of a pending crisis. Waiting until all available sites have been fully utilized will mean that there will be less time to research alternatives and select the most appropriate means of disposal both from an economical and environmental standpoint.

One viable alternative is to incinerate the Navy's solid waste. Since the RCTA requires all government agencies to employ the most efficient means of disposal and to recover as many resources as is pratical, heat recovery should be incorporated with incineration. There are several processes available to convert refuse into a usable fuel. Unfortunately, most of these processes require more than 200 TPD of refuse to be economically feasible. The only form of refuse derived fuel (RDF) that is practical for systems smaller than 200 TPD is raw refuse.

The Navy has constructed and is operating several heat recovery incineration (HRI) systems which utilize raw refuse as a fuel. Tests have indicated that these systems operate with a downtime calculated to be approximately 48% and a steam production cost of $9.13/MBtu as compared to a $8.00/MBtu production cost by conventional means. If the downtime could be reduced to 20%, it is estimated that production costs would be $5.50/MBtu and the payback period would be 6.2 years.

The Navy plants tested meet stack emission environmental standards, but the test on the HRI located at Mayport, Florida, indicated that fly ash could produce a leachate whose lead and cadmium concentrations exceed the 40 CFR 261.24 standards. This test also showed that cyclone separators are not the best means of particulate removal because the particles being emitted are smaller than the lower limit of 20 to 30 um for effective removal using these control methods.

The Navy should continue to research the utilization of RDF. With information presently available, raw refuse is the only form of refuse derived fuel that is practical for plants smaller then 200 TPD. Since most Navy bases generate less than this, the research emphasis should continue to be on small plants. More research should be conducted on the practicality and potential success of voluntary presorting of refuse before it reaches the disposal site. If this proves to be workable, heat content could be increased, moisture content could be decreased, and the chances of slagging and clinkering minimized.

Electrostatic precipitators should be utilized for air particulate control. They provide the most efficient means of removal for the small particles encountered. More research needs to be done on possible ways of

controlling lead and cadmium levels prevalent in fly ash and bottom ash. If the major contributors to these contaminants could be isolated, potential reduction could result.

HRI systems utilizing raw refuse and modular incineration are economically feasible and can have reasonable payback periods. The reliability, maintainability, and availability tests on the Mayport HRI should be repeated in another year or so to determine what affect the lack of operational experience, design problems, and start-up had on the original test results.

The author feels that the modular incineration of raw refuse with the proper amount of pre-processing has potential both as an alternate evergy source and as an alternative to disposal by landfill. Problem area in operating plants should continue to be isolated and corrected and then monitored to determine the success of the repair. If a problem continues to arise, possible changes in operating procedures should be considered. The results of these changes should be well documented in an effort to gain operational experience and an insight into required design changes.

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APPENDIX A

Data Collected from U.S. Navy Public Works Centers

Public Works Center Pearl Harbor, Hawaii

COST OF OBTAINING ELECTRIC POWER

I Power Requirements for FY 81:

Highest Peak Load FY 81 (KW)		45000
Average Peak Load FY 81 (KW)	1st Qtr	41000
	2nd Qtr	40333
	3rd Qtr	43667
	4th Qtr	44330
Average Load FY 81 (KW)	1st Qtr	29902
	2nd Qtr	30330
	3rd Qtr	31940
	4th Qtr	33525
Total Power Generated (KWH)	1st Qtr	N/A
	2nd Qtr	N/A
	3rd Qtr	N/A
	4th Qtr	N/A
Total Power Purchased (KWH)	1st Qtr	65300000
	2nd Qtr	66200000
	3rd Qtr	69800000
	4th Qtr	73300000
Anticipated growth (+) or decrease (-) in power requirements over next five years		10%. Approx 2% per year.

II Cost of Generating Electric Power for FY 81:

Operational Costs-	
Labor Costs	N/A
Fuel Costs	N/A
Percent increase in fuel cost over last three (3) years	N/A
Material Costs	N/A
Maintenance Costs-	
Labor Costs	N/A
Material Costs	N/A
Any Additional Costs-	
Labor Costs	N/A
Material Costs	N/A

Number of existing generators	N/A
Average KW rating of existing generators	N/A
Average age of existing generators	N/A
Average economic life of existing generators	N/A
Average replacement costs of existing generators	N/A
Average cost of power electricians ($/hr)	N/A

III Cost of Purchasing Electric Power for FY 81:

Cost per KWH	7.74 ¢/KWH
*Percent increase in rate over last three (3) years	75.9%
Demand charge	$1,272,783.99
*Percent increase in demand rate over last three (3) years	16.3%
Fuel charge	$16,977,181.37
*Percent increase in fuel charge over last three (3) years	404.4%

*Percent increase is calculated over last two years instead of three

IV Remarks: FY 78 Data not available

What type of system is employed for electric power generation ? (i.e., steam turbine, diesel generator, etc.)

What type of fuel is utilized ?

What is the heat rate, Btu/KWH ?

COST OF PRODUCING STEAM

I Steam Requirements for FY 81:

Average pressure required (psi)		125 psig	
Average temperature required (^{o}F)		353	
Steam produced (lbm)	1st Qtr	40,113,000 -	
	2nd Qtr	44,523,000 -	
	3rd Qtr	41,985,000 -	SEE NOTE 1
	4th Qtr	38,404,000 -	
Anticipated percent growth (+) or decreases (-) in steam requirements over next five years		-0-	

II Cost of producing steam for FY 81:

Operational Costs-		
Labor Costs	$ 348,884	
Fuel Costs	$2,517,426	
Increase in fuel cost over last three (3) years	176%	
Material Cost	$ 16,656	
Maintenance Costs-		
Labor Costs	$ 120,000	
Material Costs	$ 30,000	SEE NOTE 2
Any Additional Costs-		
Labor Costs		
Material Costs	$1,125,700	SEE NOTE 3
Number of existing boilers	12 MUSE Boilers (4 each on 3 trailers)	
Average lbm/hr rating of existing boilers	6,500	
Average age of existing boilers	N/A	
Average economic life of existing boilers	N/A	
Average replacement cost of existing boilers	N/A	
Average cost of boiler technicians ($/hr)	$25	

III Remarks:

What type of fuel is utilized? Diesel Oil

NOTES:

1. These are calculated values of steam produced based upon the total amount of fuel consumed by the temporary Mobile Utility Support Equipment (MUSE) boilers that were assumed to operate at 72% efficiency. MUSE boilers are being used to provide steam during the period the existing boilers are being replaced by MILCON P-416. The final installation will have three (3) 40,000 lbm/hr boilers (one standby) and the installation should be in operation in mid September 1982, after which more accurate data should become available.

2. The temporary MUSE boilers required more maintenance and repairs than what the permanent boilers normally would have required. Therefore, the costs shown are estimated values.

3 This cost consists of $120,500 for electricity and $1,005,200 for demineralized boiler feed water that were provided for the MUSE boilers. Demineralizers were provided by MILCON P-416 to furnish demineralized feed water for the new boilers.

REFUSE COLLECTION AND DISPOSAL

I Refuse Characterization:

Total amount of refuse collected (ft^3) FY 81	15,241,500
Total weight of refuse collected (lbm) FY 81	58,546 tons
Moisture content of refuse	1. (SEE ATTACHED SHEET)

Composition of refuse by percent-

Metal	2. (SEE ATTACHED SHHET)
Paper	
Plastic	
Leather and Rubber	
Textiles	
Wood	
Food Waste	
Yard Waste	
Glass	
Miscellaneous	

II Refuse Collection:

Cost of collection-	
If by contract cost of contract	3. (SEE ATTACHED SHEET)
If accomplished by in-house personnel	
Labor Costs	
Material Costs	
Transportation Costs	
Miscellaneous Costs	
Is refuse being segregated	NO

If refuse is segregated please explain to what extent and for what purpose-

III Refuse Disposal:

Cost of disposal-	
If by contract cost of contract	3. (SEE ATTACHED SHEET)
If accomplished by in-house personnel	
Labor Costs	
Material Costs	
Transportation Costs	
Miscellaneous Costs	

What is method of disposal- Sanitary landfill

IV Remarks:

REFUSE COLLECTION AND DISPOSAL

1. Moisture content of refuse - No moisture content of the refuse generated by Naval activities is currently available. However, in 1976, Engineering Science, Incorporated prepared a report for the NAVY at PEARL HARBOR based on a 3-day sampling of mixed refuse generated at Pearl Harbor Naval Base, Barbers Point Naval Air Station and Kaneohe Marine Corps Air Station. It reported 78%, 92% (industrial/commercial waste only), and 76% combustible material from those areas, respectively.

2. Composition of refuse - No detailed breakdown of refuse components is available. It is assumed that this information is needed to calculate the percent of combustible material, which is provided above. However, if a detailed breakdown is desired, the results of a June, 1964 study on refuse generated in Honolulu can be used. See the attached Solid Waste Composition table.

3. The refuse generated by Naval Shore activities on Oahu, Hawaii is collected and disposed of by both in-house forces (PWC PEARL) and by contract with private contractors. Five separate private contractors are currently being utilized to pick up and dispose of Navy refuse from various geographical areas on Oahu. The scattered and varied record-keeping systems preclude the collection of accurate and detailed data. The only available data is the total cost incurred to the NAVY for collection and disposal of its refuse. This amount is $2,475,000 for the collection and disposal of 15,241,500 cu. ft. of refuse for the past year. These figures include the refuse collected in-house.

Unfortunately, no cost breakdown for labor, transportation, etc., is available.

Table 6

Domestic Solid Waste Composition

Constituent	Percent by Weight		
	Honolulu - 1964[1]	National - 1975[2]	Projected National - 1990[2]
Combustible			
Paper	39.4	30.6	33.5
Yard Trimmings	36.7	19.1	18.1
Garbage	5.8	16.7	13.8
Textiles	1.7	1.5	1.7
Wood	1.7	3.7	3.7
Miscellaneous	1.1	4.1 (Plastics) 2.7 (Rubber/Leather) 6.8	6.6 (Plastics) 2.9 (Rubber/Leather) 9.5
Total Combustible	86.4	78.4	80.3
Non Combustible			
Metals	6.3	8.5 (ferrous) 1.1 (nonferrous) 9.6	8.2 (ferrous) 1.5 (nonferrous) 9.7
Glass	5.9	10.5	8.4
Misc. Inorganics	1.4	1.5	1.6
Total Non Combustible	13.6	21.6	19.7

[1]Source: "A Study of Composition and Character of Solid Waste of Oahu", Nathan Burbank, University of Hawai'i, June, 1964.

[2]Source: Midwest Research Institute, "Baseline Forcasts of Resource Recovery, 1972-1990", March 1975, p. 47.

1. COMPONENT	FY 19___ MILITARY CONSTRUCTION PROJECT DATA	2. DATE

3. INSTALLATION AND LOCATION

4. PROJECT TITLE	5. PROJECT NUMBER

REFUSE CALCULATIONS, TOTAL NAVY, OAHU

Assumptions:

1. 3.5 lb/capita-day refuse generation*
2. 3 person/housing unit
3. 150#/yd3 normal, non-compacted refuse density*
4. 300#/yd3 bulk refuse density (also PWC pickup-industrial)

*Based on Studies by the Institute for Solid Wastes of American Public Works Association. Adjusted for local conditions.

I. IN-HOUSE COLLECTION (FY-81)

30,986 tons collected and disposed of @ $8.75/ton

=$271,128 disposal only cost.

Total in-house cost = $1,559,174

Disposal cost = $ 271,128

Labor cost = $1,288,046

30,986 Tons = 206,570 yd3

II. CONTRACT COLLECTION/DISPOSAL

A. Kamakani Services

Amount = 2600 family units X 3.5#/cap-day X 3 pers/unit

X 365 days/yr = 4,982 Tons = 66,430 yd3

Cost = $156,456.

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1. COMPONENT	FY 19___MILITARY CONSTRUCTION PROJECT DATA	2. DATE
3. INSTALLATION AND LOCATION		
4. PROJECT TITLE		5. PROJECT NUMBER

B. Bay Cities Disposal Co. (Lots 4 & 5).

Amount = (6,900 yd3 + 37 Tons Bulk)/month

= 82,800 + 2,960 = 85,760 yd3/yr.

Cost = $243,716

C. Kane's Refuse (Lots 1 & 3)

Amount = (11,400 yd3 + 56 Tons Bulk)/month

= 136,800 + 4,480 = 141,280 yd3/yr.

Cost = $326,598

D. Honolulu Disposal (Lot 6)

Amount = (2,300 yd3 + 11 Tons Bulk)/month

= 27,600 yd3 + 880 yd3 = 28,480 yd3/yr.

Cost = $109,075

E. The Refuse Inc. (Lot 2)

Amount = 2900 yd3 + 15 Tons/month =

34,800 + 1200 = 36,000 yd3/yr.

Cost = $79,980.

SUMMARY

Total Amount Collected (Yr.) = 564,500 yd3

Total Cost (Yr.) = $2,475,000.

Total Amount Collected (Yr.) in Weight = 58,546 Tons.

Public Works Center Pennascola, Fla.

COST OF OBTAINING ELECTRIC POWER

I Power Requirements for FY 81:

Highest Peak Load FY 81 (KW)		29,200
Average Peak Load FY 81 (KW)	1st Qtr	24,500
	2nd Qtr	20,700
	3rd Qtr	25,700
	4th Qtr	28,800
Average Load FY 81 (KW)	1st Qtr	16,387
	2nd Qtr	13,723
	3rd Qtr	16,013
	4th Qtr	18,457
Total Power Generated (KWH)	1st Qtr	19,421,600
	2nd Qtr	13,177,000
	3rd Qtr	14,997,000
	4th Qtr	21,370,000
Total Power Purchased (KWH)	1st Qtr	16,204,800
	2nd Qtr	16,464,000
	3rd Qtr	20,380,800
	4th Qtr	19,382,400
Anticipated growth (+) or decrease (-) in power requirements over next five years		-

II Cost of Generating Electric Power for FY 81:

Operational Costs-	
Labor Costs	429,097
Fuel Costs	2,042,410
Percent increase in fuel cost over last three (3) years	51%
Material Costs	15,011
Maintenance Costs-	
Labor Costs	106,909
Material Costs	50,997
Any Additional Costs-	
Labor Costs	
Material Costs	1,164,841

Number of existing generators	3
Average KW rating of existing generators	9,000
Average age of existing generators	38
Average economic life of existing generators	40
Average replacement costs of existing generators	5 million
Average cost of power electricians ($/hr)	

III Cost of Purchasing Electric Power for FY 81:

		FY'80	FY'
Cost per KWH	44.3765	36.6074	
			33.54
Percent increase in rate over last three (3) years	32%	5.00	2.9
Demand charge	5.00	.00178	.0092
Percent increase in demand rate over last three (3) years	68%		
Fuel charge	.00325		
Percent increase in fuel charge over last three (3) years	-35%		

IV Remarks:

What type of system is employed for electric power generation ? (i.e., steam turbine, diesel generator, etc.) Steam Turbine

What type of fuel is utilized ? Natural Gas and F.O. #4

What is the heat rate, Btu/KWH ? 10.

COST OF PRODUCING STEAM

I Steam Requirements for FY 81:

Average pressure required (psi)		620
Average temperature required (^{o}F)		820
Steam produced (lbm)	1st Qtr	535,241
	2nd Qtr	551,188
	3rd Qtr	543,738
	4th Qtr	506,307
Anticipated percent growth (+) or decrease (-) in steam requirements over next five years		+10

II Cost of producing steam for FY 81:

Operational Costs-	
Labor Costs	556,175
Fuel Costs	6,109,840
Increase in fuel cost over last three (3) years	
Material Costs	332,539
Maintenance Costs-	
Labor Costs	184,990
Material Costs	128,248
Any Additional Costs-	
Labor Costs	
Material Costs	2,897,132
Number of existing boilers	3
Average lbm/hr rating of existing boilers	157
Average age of existing boilers	24 years
Average economic life of existing boilers	40 years
Average replacement cost of existing boilers	4 million
Average cost of boiler technicians ($/hr)	

III Remarks:

What type of fuel is utilized ? Natural gas and F.O. #4

REFUSE COLLECTION AND DISPOSAL

I Refuse Characterization:

Total amount of refuse collected (ft^3) FY 81	537,045 CY
Total weight of refuse collected (lbm) FY 81	Not Determined
Moisture content of refuse	" "
Composition of refuse by percent-	
Metal	" "
Paper	" "
Plastic	" "
Leather and Rubber	" "
Textiles	" "
Wood	" "
Food Waste	" "
Yard Waste	" "
Glass	" "
Miscellaneous	" "

II Refuse Collection:

Cost of collection-	
If by contract cost of contract	$430,955.30
If accomplished by in-house personnel	
Labor Costs	-
Material Costs	-
Transportation Costs	-
Miscellaneous Costs	-

Is refuse being segregated — No

If refuse is segregated please explain to what extent and for what purpose-

III Refuse Disposal:

Cost of disposal-	
If by contract cost of contract	Included above
If accomplished by in-house personnel	
Labor Costs	-
Material Costs	-
Transportation Costs	-
Miscellaneous Costs	-

What is method of disposal- County Landfill

IV Remarks:

Public Works Center San Francisco

COST OF OBTAINING ELECTRIC POWER

NAS ALAMEDA

I Power Requirements for FY 81:

Highest Peak Load FY 81 (KW)		23,200
Average Peak Load FY 81 (KW)	1st Qtr	21,333
	2nd Qtr	21,600
	3rd Qtr	22,133
	4th Qtr	21,867
Average Load FY 81 (KW)	1st Qtr	14,000
	2nd Qtr	15,800
	3rd Qtr	14,800
	4th Qtr	15,300
Total Power Generated (KWH)	1st Qtr	N/A
	2nd Qtr	
	3rd Qtr	
	4th Qtr	
Total Power Purchased (KWH)	1st Qtr	27,480,000
	2nd Qtr	27,096,000
	3rd Qtr	29,208,000
	4th Qtr	28,608,000
Anticipated growth (+) or decrease (-) in power requirements over next five years		+10%

II Cost of Generating Electric Power for FY 81:

Operational Costs-	
Labor Costs	N/A
Fuel Costs	
Percent increase in fuel cost over last three (3) years	
Material Costs	
Maintenance Costs-	
Labor Costs	
Material Costs	
Any Additional Costs-	
Labor Costs	
Material Costs	

Number of existing generators ______________

Average KW rating of existing generators ______________

Average age of existing generators ______________

Average economic life of existing generators ______________

Average replacement costs of existing generators ______________

Average cost of power electricians ($/hr) ______________

III Cost of Purchasing Electric Power for FY 81:

Cost per KWH	$.052/KWH
Percent increase in rate over last three (3) years	66%
Demand charge	$7,800 for 1st 4,000KW, $2.00/KW for balance
Percent increase in demand rate over last three (3) years	32%
Fuel charge	$.0343/KWH
Percent increase in fuel charge over last three (3) years	156%

IV Remarks:

What type of system is employed for electric power generation ? N/A
(i.e., steam turbine, diesel generator, etc.)

What type of fuel is utilized ? N/A

What is the heat rate, Btu/KWH ? N/A

COST OF PRODUCING STEAM

NAS ALAMEDA, Bldg. 10

I Steam Requirements for FY 81:

Average pressure required (psi)		100
Average temperature required (^{o}F)		$338^{o}F$
Steam produced (lbm)	1st Qtr	164.5×10^6
	2nd Qtr	191.5×10^6
	3rd Qtr	207.1×10^6
	4th Qtr	122.8×10^6
Anticipated percent growth (+) or decrease (-) in steam requirements over next five years		+10%

II Cost of producing steam for FY 81:

Operational Costs-	
Labor Costs	$476,500
Fuel Costs	$4.54/Million Btu's
Increase in fuel cost over last three (3) years	77%
Material Costs	$50,800
Maintenance Costs-	
Labor Costs	$72,400
Material Costs	$10,275
Any Additional Costs-	
Labor Costs	N/A
Material Costs	
Number of existing boilers	4
Average lbm/hr rating of existing boilers	100,000 lb/hr each
Average age of existing boilers	2-9 years, 2-38 years
Average economic life of existing boilers	25 years
Average replacement cost of existing boilers	$1,175,000
Average cost of boiler technicians ($/hr)	$24.83/hr

III Remarks:

What type of fuel is utilized ? Primary fuel- natural gas
Standby fuel- fuel oil No.2

REFUSE COLLECTION AND DISPOSAL

I Refuse Characterization:

Total amount of refuse collected (Yd^3) FY 81	697,469
Total weight of refuse collected (lbm) FY 81	N/A
Moisture content of refuse	N/A
Composition of refuse by percent-	
Metal	N/A
Paper	
Plastic	
Leather and Rubber	
Textiles	
Wood	
Food Waste	
Yard Waste	
Glass	
Miscellaneous	

II Refuse Collection:

Cost of collection-	
If by contract cost of contract	\$379,743
If accomplished by in-house personnel	
Labor Costs	735,745
Material Costs	5,014
Transportation Costs	274,974
Miscellaneous Costs	60,857
Is refuse being segregated	No

If refuse is segregated please explain to what extent and for what purpose-

III Refuse Disposal:

Cost of disposal-	
If by contract cost of contract	298,437
If accomplished by in-house personnel	
Labor Costs	
Material Costs	
Transportation Costs	
Miscellaneous Costs	

What is method of disposal- Refuse is placed in either large trailers or compaction trailers and hauled to the City Dump in San Leandro.

IV Remarks:

Public Works Center Yokosuka

COST OF OBTAINING ELECTRIC POWER

I Power Requirements for FY 81:

Highest Peak Load FY 81 (KW)		27,000
Average Peak Load FY 81 (KW)	1st Qtr	15,300
	2nd Qtr	17,300
	3rd Qtr	16,100
	4th Qtr	24,200
Average Load FY 81 (KW)	1st Qtr	10,900
	2nd Qtr	10,380
	3rd Qtr	10,010
	4th Qtr	14,060
Total Power Generated (KWH)	1st Qtr	4,571,305
	2nd Qtr	3,512,945
	3rd Qtr	3,224,139
	4th Qtr	6,182,169
Total Power Purchased (KWH)	1st Qtr	18,459,088
	2nd Qtr	17,609,248
	3rd Qtr	17,593,940
	4th Qtr	23,405,416
Anticipated growth (+) or decrease (-) in power requirements over next five years		+5%

II Cost of Generating Electric Power for FY 81:

Operational Costs-	
Labor Costs	$150,009
Fuel Costs	$1,688,898
Percent increase in fuel cost over last three (3) years	+92%
Material Costs	$50,145
Maintenance Costs-	
Labor Costs	$117,487
Material Costs	$197,411
Any Additional Costs-	
Labor Costs	18,287
Material Costs	9,741

Enclosure (1)

Number of existing generators	5
Average KW rating of existing generators	2,500KWx2 1,500KWx3
Average age of existing generators	13 years
Average economic life of existing generators	25 years
Average replacement costs of existing generators	$2,944,000
Average cost of power electricians ($/hr)	$9.65

III Cost of Purchasing Electric Power for FY 81:

Cost per KWH	$0.07082
Percent increase in rate over last three (3) years	+66%
Demand charge	$1,282,229
Percent increase in demand rate over last three (3) years	+68%
Fuel charge	N/A
Percent increase in fuel charge over last three (3) years	N/A

IV Remarks:

What type of system is employed for electric power generation ? (i.e., steam turbine, diesel generator, etc.)

Diesel generators

What type of fuel is utilized ?

FS-1

What is the heat rate, Btu/KWH ?

10,725 BTU/KWH

COST OF PRODUCING STEAM

I Steam Requirements for FY 81:

Average pressure required (psi)		140
Average temperature required (^{o}F)		361
Steam produced (lbm)	1st Qtr	208,005,929
	2nd Qtr	348,020,158
	3rd Qtr	174,854,708
	4th Qtr	162,446,217
Anticipated percent growth (+) or decrease (-) in steam requirements over next five years		+6%

II Cost of producing steam for FY 81:

Operational Costs-	
Labor Costs	$ 494,061
Fuel Costs	$8,824,627
Increase in fuel cost over last three (3) years	+70%
Material Costs	$32,980
Maintenance Costs-	
Labor Costs	$84,062
Material Costs	$29,800
Any Additional Costs-	
Labor Costs	$7,850
Material Costs	$3,135
Contract work	$26,500
Number of existing boilers	9
Average lbm/hr rating of existing boilers	46,540
Average age of existing boilers	7 years
Average economic life of existing boilers	20 years
Average replacement cost of existing boilers	$412,600
Average cost of boiler technicians ($/hr)	$9.65

III Remarks:

What type of fuel is utilized ?

FS-1

REFUSE COLLECTION AND DISPOSAL

I Refuse Characterization:

Total amount of refuse collected (ft^3) FY 81 — 2,948,940

Total weight of refuse collected (lbm) FY 81 — 27,305,000 Lbs

Moisture content of refuse — Unknown

Composition of refuse by percent-

Metal	0.2
Paper	2.0
Plastic	1.5
Leather and Rubber	1.5
Textiles	1.0
Wood	15.0
Food Waste	15.0
Yard Waste	15.0
Glass	10.0
Miscellaneous	38.8

II Refuse Collection:

Cost of collection-
If by contract cost of contract — $289,700
If accomplished by in-house personnel — (Includes cost of transportation to City's Landfill area.)
Labor Costs
Material Costs
Transportation Costs
Miscellaneous Costs

Is refuse being segregated — Yes

If refuse is segregated please explain to what extent and for what purpose- — Segregation is done for recycling purpose such as paper, metal, and aluminum.

III Refuse Disposal:

Cost of disposal-
If by contract cost of contract — Free
If accomplished by in-house personnel
Labor Costs
Material Costs
Transportation Costs
Miscellaneous Costs

What is method of disposal- — Landfill

IV Remarks:

Public Works Center Subic Bay, Philippines

COST OF OBTAINING ELECTRIC POWER

(TOTALS FOR SUBIC/CUBI, SAN MIGUEL, TARLAC AND STA RITA)

I Power Requirements for FY 81:

Highest Peak Load FY 81 (KW)		55,000
Average Peak Load FY 81 (KW)	1st Qtr	49,665
	2nd Qtr	46,665
	3rd Qtr	52,330
	4th Qtr	51,000
Average Load FY 81 (KW)	1st Qtr	34,790
	2nd Qtr	32,190
	3rd Qtr	36,100
	4th Qtr	34,270
Total Power Generated (KWH)	1st Qtr	22,983,300 (91 billing days)
	2nd Qtr	12,768,000 (91 billing days)
	3rd Qtr	17,833,600 (91 billing days)
	4th Qtr	13,975,900 (98 billing days)
Total Power Purchased (KWH)	1st Qtr	53,156,100
	2nd Qtr	57,355,200
	3rd Qtr	61,399,700
	4th Qtr	66,484,700
Anticipated growth (+) or decrease (-) in power requirements over next five years		+16,000 KW

II Cost of Generating Electric Power for FY 81:

Operational Costs-(Production)	
Labor Costs	$409,573.00
Fuel Costs	$5,693,981.00
Percent increase in fuel cost over last three (3) years	
Material Costs	$349,060.00
Maintenance Costs-(Production)	
Labor Costs	$279,749.00
Material Costs	$676,583.00
Any Additional Costs- (Distribution)	
Labor Costs	$369,875.00
Material Costs	$460,777.00

Number of existing generators	See attach (1)
Average KW rating of existing generators	
Average age of existing generators	
Average economic life of existing generators	
Average replacement costs of existing generators	
Average cost of power electricians ($/hr)	3.75

III Cost of Purchasing Electric Power for FY 81:

Cost per KWH	$0.05824
Percent increase in rate over last three (3) years	87.38%
Demand charge	See note (1)
Percent increase in demand rate over last three (3) years	631.72%
Fuel charge	$0.01239 per kwh
Percent increase in fuel charge over last three (3) years	105.4%

IV Remarks:

What type of system is employed for electric power generation ? (i.e., steam turbine, diesel generator, etc.)

Diesel Generators

What type of fuel is utilized ?

For 6-4400 KW Nordberg units - NSFO
All other units - DFM

What is the heat rate, Btu/KWH ?

NSFO - 147500

DFM - 136400

NOTE: (1) NPC DEMAND CHARGE

FY79 - First 1000 KW of billing demand @ ₱5.63 per KW
Next 9000 KW of billing demand @ 3.38 per KW
All excess KW of billing demand @ 1.13 per KW
FY81 - First 1000 KW of billing demand @ ₱18.00 per KW
Next 9000 KW of billing demand @ 19.00 per KW
All excess KW of billing demand @ 20.10 per KW

FY79 Rate of Exchange - ₱7.376/$
FY81 Rate of Exchange - ₱8.05125/$

ON-BASE GENERATORS

A. SUBIC MAIN PLANT

Unit No.	Manufacturer	Rated KW	Normal KW	Emergency KW	Remarks
1	Nordberg	4,400	3,700	4,000	A
2	Nordberg	4,400	3,700	4,000	A
3	Nordberg	4,400	3,700	4,000	A
4	Nordberg	4,400	3,700	4,000	A
5	Nordberg	4,400	3,960	4,400	
6	Nordberg	4,400	3,960	4,400	
	Subtotal	26,400	22,720	24,800 KW	

B. SUBIC PEAKING PLANT

Unit No.	Manufacturer	Rated KW	Normal KW	Emergency KW	Remarks
1	GM-EMD	2,000	1,800	2,000	
2	GM-EMD	2,000	1,800	2,000	
3	GM-EMD	2,000	1,800	2,000	
4	GM-EMD	2,000	1,800	2,000	
5	GM-EMD	2,000	1,800	2,000	
6	GM-EMD	2,000	1,800	2,000	
7	GM-EMD	1,500	1,400	1,500	*
8	GM-EMD	2,500	2,500	2,500	*
9	GM-EMD	2,500	2,500	2,500	*
	Subtotal	18,500	17,200	18,500	

Attachment (1)

C. CUBI MAIN PLANT

Unit No.	Manufacturer	Rated KW	Normal KW	Emergency KW	Remarks
1	Worthington	520	500	520	
2	Worthington	520	500	520	
3	Worthington	700	600	650	
4	Worthington	700	600	650	
5	Worthington	600	500	550	
	Subtotal	3,040	2,700	2,890 KW	

D. CUBI PEAKING PLANT

Unit No.	Manufacturer	Rated KW	Normal KW	Emergency KW	Remarks
6	GM-EMD	1,000	900	1,000	
7	GM-EMD	1,000	900	1,000	
8	Enterprise	1,000	700	800	B
9	GM-EMD	1,500	1,400	1,500	*
10	GM-EMD	2,500	2,500	2,500	*
11	GM-EMD	2,500	2,500	2,500	
	Subtotal	9,500	8,900	9,300	
	Cubi/Cubi P.P. TOTAL	54,440	51,520	55,490	

E. GRANDE ISLAND POWER PLANT

UNIT NO.	Manufacturer	RATED KW	NORMAL KW	EMERGENCY KW	REMARKS
1	Fairbanks-Morse	96	96	96	
2	Fairbanks-Morse	249	246	249	
3	Fairbanks-Morse	249	246	249	
	Subtotal	1,694	1,488	1,694	

F. SAN MIGUEL PLANT

UNIT NO.	Manufacturer	RATED KW	NORMAL KW	EMERGENCY KW	REMARKS
1	Nordberg	675	600	650	
2	Nordberg	675	600	650	A
3	-do-	675	600	650	
4	-do-	675	600	650	
5	-do-	675	600	650	
6	-do-	675	600	650	
7	-do-	675	600	650	
8	-do-	1,000	900	950	
10	GM-EMD	750	600	600	B
11	-do-	750	700	750	
	Subtotal	7,225	6,400	6,850	

G. TARLAC PLANT

1	Nordberg	500 KW	400	450
2	-do-	500	400	450
3	-do-	500	400	450
4	-do-	500	400	450
5	-do-	500	400	450
6	-do-	2,500	1,800	2,000
7	-do-	2,500	1,800	2,000
8	-do-	2,500	1,800	2,000
	Subtotal	10,000	7,400	8,250

H. STA RITA PLANT

UNIT NO.	Manufacturer	RATED KW	NORMAL KW	EMERGENCY KW	REMARKS
1	Nordberg	250	180	200	
2	-do-	250	180	200	
3	General Motor	200	150	175	
	Subtotal	700	510	575	

REMARKS:

A - Derated due to advanced number of running hours.

B - Derated due to undersized cooling system.

C - Obsolete/unreliable units.

* - MUSE

Age cannot be calculated since most of the units were transferred from other commands.

COST OF PRODUCING STEAM
(FOR SUBIC/CUBI/SAN MIGUEL)

I Steam Requirements for FY 81: (For steam plt/boiler over 3.5 MIL BTU/HR capacity)

Average pressure required (psi)		125 PSI
Average temperature required (^oF)		350^oF
Steam produced (lbm)	1st Qtr	57544 MBTU
	2nd Qtr	59281 MBTU
	3rd Qtr	57925 MBTU
	4th Qtr	62637 MBTU
Anticipated percent growth (+) or decrease (-) in steam requirements over next five years		25% Growth

II Cost of producing steam for FY 81:

Operational Costs-	
Labor Costs	$85664.00
Fuel Costs	$1715921.00
Increase in fuel cost over last three (3) years	$0.41 to $0.88/Gal
Material Costs	$29108.00
Maintenance Costs-	
Labor Costs	$80.00
Material Costs	$8289.00
Any Additional Costs- (Distribution)	
Labor Costs (Operation & Maintenance)	$110.00
Material Costs (Operation & Maintenance)	$1285.00
Interutility Transfer (Elec & Water)	$74108.00
Number of existing boilers (Under PWC Plant Account)	15
Average lbm/hr rating of existing boilers	5893 Lbs/Hr
Average age of existing boilers	20 Yrs
Average economic life of existing boilers	
Average replacement cost of existing boilers	
Average cost of boiler technicians ($/hr)	$1.01/Hr

III Remarks:

What type of fuel is utilized ?
Navy Special Fuel Oil (NSFO No. 6), Heat Content = 147500 BTU/Gal

COST OF PRODUCING STEAM
(FOR SUBIC/CUBI)

I Steam Requirements for FY 81:(For Steam Plant/Boiler 750,000 to 3.5 MIL BTU/HR CAPACITY)

Average pressure required (psi)		40 PSI
Average temperature required (^{o}F)		286^{o}F
Steam produced (lbm)	1st Qtr	6600 MBTU
	2nd Qtr	7187 MBTU
	3rd Qtr	6958 MBTU
	4th Qtr	6743 MBTU
Anticipated percent growth (+) or decrease (-) in steam requirements over next five years		None

II Cost of producing steam for FY 81:

Operational Costs-	
Labor Costs	$26837.00
Fuel Costs	$364277.00
Increase in fuel cost over last three (3) years	$0.45 to $1.23/Gal
Material Costs	$9555.00
Maintenance Costs-	
Labor Costs	$49692.00
Material Costs	$52080.00
Any Additional Costs- (Distribution)	
Labor Costs (Operation & Maintenance)	$40568.00
Material Costs(Operation & Maintenance)	$46652.00
Interutility Transfer (Elec & Water)	$11941.00
Number of existing boilers	6
Average lbm/hr rating of existing boilers	2009 Lbs/Hr
Average age of existing boilers	20 Yrs
Average economic life of existing boilers	
Average replacement cost of existing boilers	
Average cost of boiler technicians ($/hr)	$1.01/Hr

III Remarks:

What type of fuel is utilized ?

Diesel fuel oil (DFM No. 2), Heat Content = 136400 BTU/Gal

PUBLIC WORKS CENTER SAN DIEGO
COST OF OBTAINING ELECTRIC POWER

I Power Requirements for FY 81:

Highest Peak Load FY 81 (KW)		29795 Naval Station only
Average Peak Load FY 81 (KW)	1st Qtr	26246
	2nd Qtr	26941
	3rd Qtr	23760
	4th Qtr	27860
Average Load FY 81 (KW)	1st Qtr	Not Available
	2nd Qtr	"
	3rd Qtr	"
	4th Qtr	"
Total Power Generated (KWH)	1st Qtr	None
	2nd Qtr	"
	3rd Qtr	"
	4th Qtr	"
Total Power Purchased (KWH)	1st Qtr	59275000
	2nd Qtr	59801204
	3rd Qtr	46234680
	4th Qtr	55812842
Anticipated growth (+) or decrease (-) in power requirements over next five years		+10% Annual Growth

II Cost of Generating Electric Power for FY 81:

Operational Costs-	
Labor Costs	PWC does not generate electricity.
Fuel Costs	
Percent increase in fuel cost over last three (3) years	
Material Costs	
Maintenance Costs-	
Labor Costs	
Material Costs	
Any Additional Costs-	
Labor Costs	
Material Costs	

ENCLOSURE (1)

Number of existing generators	
Average KW rating of existing generators	
Average age of existing generators	
Average economic life of existing generators	
Average replacement costs of existing generators	
Average cost of power electricians ($/hr)	

III Cost of Purchasing Electric Power for FY 81:

Cost per KWH	$ .091
Percent increase in rate over last three (3) years	86%
Demand charge	$7.67/KW
Percent increase in demand rate over last three (3) years	95%
Fuel charge	$1.37
Percent increase in fuel charge over last three (3) years	9%

IV Remarks:

What type of system is employed for electric power generation ? (i.e., steam turbine, diesel generator, etc.)

What type of fuel is utilized ? N/A

What is the heat rate, Btu/KWH ? N/A

COST OF PRODUCING STEAM

I Steam Requirements for FY 81:

Average pressure required (psi)	150 psi	
Average temperature required (^{o}F)	360°F	
Steam produced (lbm) 1st Qtr	18059 MBTU	Gross Plant Production
2nd Qtr	70932 MBTU	
3rd Qtr	58075 MBTU	
4th Qtr	38787 MBTU	
Anticipated percent growth (+) or decrease (-) in steam requirements over next five years	0	

II Cost of producing steam for FY 81: (purchased) $11,901,183

Operational Costs-	
Labor Costs	Not available
Fuel Costs	"
Increase in fuel cost over last three (3) years	"
Material Costs	"
Maintenance Costs-	
Labor Costs	"
Material Costs	"
Any Additional Costs-	
Labor Costs	"
Material Costs	"
Number of existing boilers	"
Average lbm/hr rating of existing boilers	"
Average age of existing boilers	"
Average economic life of existing boilers	"
Average replacement cost of existing boilers	"
Average cost of boiler technicians ($/hr)	"

III Remarks:

What type of fuel is utilized ? N/A (Purchased Steam - $8.00/MBTU)

ENCLOSURE (2)

REFUSE COLLECTION AND DISPOSAL

I Refuse Characterization:

Total amount of refuse collected (ft^3) FY 81	600,000 Cubic Yards
Total weight of refuse collected (lbm) FY 81	290,000 Tons
Moisture content of refuse	Above Normal

Composition of refuse by percent-

Metal	6%
Paper	45%
Plastic	5%
Leather and Rubber	10%
Textiles	15%
Wood	10%
Food Waste	3%
Yard Waste	3%
Glass	3%
Miscellaneous	

II Refuse Collection:

Cost of collection-

If by contract cost of contract	N/A
If accomplished by in-house personnel	
Labor Costs	$245,000
Material Costs	$ 45,000
Transportation Costs	$200,000
Miscellaneous Costs	—

Is refuse being segregated — No

If refuse is segregated please explain to what extent and for what purpose-

III Refuse Disposal:

Cost of disposal-

If by contract cost of contract	N/A
If accomplished by in-house personnel	
Labor Costs	N/A
Material Costs	N/A
Transportation Costs	N/A
Miscellaneous Costs	N/A

What is method of disposal- Landfill

ENCLOSURE (3)

IV Remarks:

Public Works Center, Guam
COST OF OBTAINING ELECTRIC POWER

I Power Requirements for FY 81:

Highest Peak Load FY 81 (KW)		72,000
Average Peak Load FY 81 (KW)	1st Qtr	65,600
	2nd Qtr	66,000
	3rd Qtr	65,700
	4th Qtr	65,700
Average Load FY 81 (KW)	1st Qtr	51,200
	2nd Qtr	48,500
	3rd Qtr	50,400
	4th Qtr	50,000
Total Power Generated (KWH)	1st Qtr	12,500,000
	2nd Qtr	48,000,000
	3rd Qtr	15,500,000
	4th Qtr	7,450,000
Total Power Purchased (KWH)	1st Qtr	110,737,460
	2nd Qtr	104,708,850
	3rd Qtr	109,000,000
	4th Qtr	107,460,230
Anticipated growth (+) or decrease (-) in power requirements over next five years		-10%

II Cost of Generating Electric Power for FY 81:

Operational Costs-	
Labor Costs	50,000
Fuel Costs	1,988,000
Percent increase in fuel cost over last three (3) years	100%
Material Costs	20,000
Maintenance Costs-	
Labor Costs	200,000
Material Costs	300,000
Any Additional Costs-	
Labor Costs	
Material Costs	

ENCLOSURE (1)

Number of existing generators	5
Average KW rating of existing generators	18,000
Average age of existing generators	24 Years
Average economic life of existing generators	30 Years
Average replacement costs of existing generators	7,000,000
Average cost of power electricians ($/hr)	$10/Hr.

III Cost of Purchasing Electric Power for FY 81:

Cost per KWH	$.12
Percent increase in rate over last three (3) years	40%
Demand charge	110,000/Month
Percent increase in demand rate over last three (3) years	-10%
Fuel charge	1.37/Gallon
Percent increase in fuel charge over last three (3) years	100%

IV Remarks:

What type of system is employed for electric power generation ? (i.e., steam turbine, diesel generator, etc.)

What type fuel is utilized ? Fuel oil.

What is the heat rate, Btu/KWH ? 10,000

COST OF PRODUCING STEAM

I Steam Requirements for FY 81:

Average pressure required (psi)		164 PSIA
Average temperature required (°F)		350°F
Steam produced (lbm)	1st Qtr	17×10^6
	2nd Qtr	17.6×10^6
	3rd Qtr	18×10^6
	4th Qtr	14.7×10^6
Anticipated percent growth (+) or decrease (-) in steam requirements over next five years		+ 10%

II Cost of producing steam for FY 81:

Operational Costs-	
Labor Costs	222,706
Fuel Costs	332,999
Increase in fuel cost over last three (3) years	100%
Material Costs	3926
Maintenance Costs-	
Labor Costs	117,552
Material Costs	79,717
Any Additional Costs-	
Labor Costs	150,570
Material Costs	229,618
Number of existing boilers	7
Average lbm/hr rating of existing boilers	8,000
Average age of existing boilers	1 Year
Average economic life of existing boilers	25 Years
Average replacement cost of existing boilers	200,000
Average cost of boiler technicians ($/hr)	10/Hr.

III Remarks:

What type of fuel is utilized ? Disel Fuel.

AD-A140 126 UTILIZATION OF REFUSE DERIVED FUELS BY THE UNITED STATES NAVY(U) COLORADO UNIV AT BOULDER DEPT OF CIVIL ENGINEERING D L LEHR JUL 83 N66314-70-A-0062 2/2

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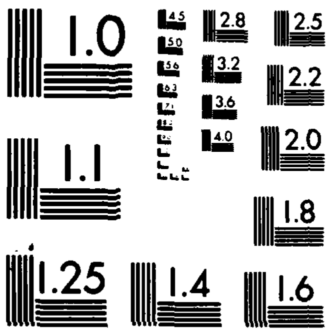

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

REFUSE COLLECTION AND DISPOSAL

I Refuse Characterization:

Total amount of refuse collected (ft^3) FY 81	510,268 c.y.
Total weight of refuse collected (lbm) FY 81	unknown
Moisture content of refuse	unknown

Composition of refuse by percent-

Metal	5%
Paper	20%
Plastic	5%
Leather and Rubber	2%
Textiles	5%
Wood	20%
Food Waste	20%
Yard Waste	20%
Glass	1%
Miscellaneous	2%

II Refuse Collection:

Cost of collection-

If by contract cost of contract	N/A
If accomplished by in-house personnel	
Labor Costs	$885,589.00
Material Costs	*
Transportation Costs	*
Miscellaneous Costs	*

*Included in total as cost are based on c.y. and consolidated.

Is refuse being segregated: No

If refuse is segregated please explain to what extent and for what purpose-

III Refuse Disposal:

Cost of disposal-

If by contract cost of contract	N/A
If accomplished by in-house personnel	$212,995.00
Labor Costs	*
Material Costs	*
Transportation Costs	*
Miscellaneous Costs	*

*Included in total as cost are based on c.y. and consolidated.

What is method of disposal- EPA approved sanitary landfill

Total Amount of refuse disposed of (ft^3) FY81: 535,189 c.y.

IV Remarks:

APPENDIX B

DATA ANALYSIS

PWC LOCATION	REFUSE COLLECTED (TONS) (1)	REFUSE GENERATION RATE (TONS/DAY)	COST OF DISPOSAL $	COST OF DISPOSAL $/TON	TYPE OF DISPOSAL
San Diego, CA.	60,000	164	490,000	8.17	Landfill
Guam	51,026	140	885,590	17.35	Landfill
Yokosuka, Japan	13,652 (2)	37	289,700	21.22	Landfill
Pearl Harbor, Hawaii	58,546 (2)	160	2,475,000	42.27	Landfill
San Franscisco, CA.	69,746	191	1,456,333	20.88	Landfill
Pennsacola, FL.	53,704	147	430,955	8.02	Landfill

(1) Bulk density of refuse assumed to equal 200 lb/yd^3.

(2) Reported in terms of lbm.

TABLE B-1

Public Works Centers Refuse Generation Rate and Disposal Costs

TABLE B-2

PUBLIC WORKS CENTERS UTILITY RATES

PWC LOCATION	RATE $/KWH	ELECTRICITY COST DEMAND (1) $/KWH	FUEL CHARGE (2) $/KWH	TOTAL AVE RATE (3) $/KWH	COST OF STEAM (4) $/MBTU
San Diego, CA.	0.091	7.67	0.003	0.097	8.00 (5)
Guam	0.12	5.00	0.003	0.123	--
Yokosuka, Japan	0.07	5.86	--	0.14	8.92
Subic Bay, Philippines (6)	0.06	2.47	0.012	0.078	--
Subic Bay, Philippines (7)	--	--	--	0.12	7.94
Pearl Harbor, HI.	0.08	2.50	0.06	0.14	--
San Francisco, CA.	0.052	2.00	0.0343	0.09	8.69
Pennsacola, FL. (8)	0.04	5.00	0.00325	0.07	--
Pennsacola, FL. (9)	--	--	--	0.053	--

NOTES:

(1) Ave Demand = $\dfrac{\text{Ave Monthly Demand Charge}}{\text{Ave Monthly Peak Load}}$

(2) For San Diego and Guam used $1.37/gal and 136,400 Btu/gal

(3) Ave Rate = $\dfrac{\text{(Rate x total annual use)+(Ave monthly peak load x 12 x Ave Demand Rate)+(Fuel rate x total annual use)}}{\text{Total Annual Use}}$

(4) Steam is at 160 psia and 363°F thus the enthalpy equals 1195 Btu/lbm

(5) Steam is purchased

(6) Purchased utility rates

(7) Generated utility rates = $\dfrac{\text{Total Generation Costs}}{\text{Total Annual Consumption}}$

(8) Purchased utility rates

(9) Generated utility rates = $\dfrac{\text{Total Generation Costs}}{\text{Total Annual Consumption}}$

APPENDIX C

SAMPLE CALCULATIONS

Mass and energy balance for Incinerator operation

1) Heat available:

$M_R \times h_{cR} = H_R$

M_R = mass of refuse into system

h_{cR} = heat value of refuse

H_R = total heat available

2) Required Air:

$foM_R \times m_a = M_a$

fo = weight fraction organics

M_R = mass of refuse into system

ma = lb dry air reuqired per lb organics

Ma = total mass dry air required

3) Heat required:

a) Raise ambient air temperature

Ma x hca x (Ts - Ta) = Ha

Ma = total mass air required

hca = specific heat of air

Ts = stack temperature

Ta = ambient temperature

Ha = heat required to raise air temperature to stack temperature

b) Raise temperature of organics to stack temperature

$foM_R \times hc_o \times (Ts - Ti) = Ho$

fo = weight fraction organics

M_R = mass of refuse into system

hc_o = specific heat of organics

Ts = stack temperature

Ti = initial refuse temperature

Ho = heat required to raise organic temperature to stack temperature

c) Raise temperature of water vapor in air to stack temperature:

$$faMa \times hc_{wv} \times (Ts - Ta) = Haw$$

$$fa = \frac{\text{lb water entrained}}{\text{lb dry air}}$$

Ma = total mass dry air required

hc_{wv} = specific heat of water vapor

Ts = stack temperature

Ta = ambient temperature

Haw = heat required to raise water vapor in air to stack temperature

d) Raise temperature of inorganics to disposal temperature:

$$f_{Io} M_R \times hc_{Io} \times (Tss - Ti) = H_{Io}$$

f_{Io} = weight fraction inorganics

M_R = mass of refuse into system

hc_{Io} = disposal temperature

Tss = disposal temperature

Ti = initial refuse temperature

H_{Io} = heat required to raise inorganics to disposal temperature

e) Raise water to boiling temperature:

$$fw\ M_R \times haw \times (Tb - Ti) = Hb$$

fw = weight fraction moisture content of refuse

M_R = mass of refuse into system

hcw = specific heat of water

Tb = boiling temperature

Ti = initial refuse temperature

Hb = heat required to raise water to boiling temperature

f) Heat required to evaporate water:

$$fw\ M_R \times hv = Hv$$

fw = weight fraction moisture content of refuse

Mr = mass of refuse into system

hv = latent heat of vaporization

Hv = heat required for vaporization

g) Raise temperature of water vapor to stack temperature:

$$fw\ M_R \times hcwv \times (Ts - Tb) = Haw$$

fw = weight fraction moisture content of refuse

M_R = mass of refuse into system

Hcwv = specific heat of water vapor

Ts = stack temperature

Tb = boiling temperature

Haw = heat required to raise temperature of water vapor to stack temperature

h) Evaporate formed water:

$$(Ha + Ho + H_Io + Hb + Hv + Haw) \times Mw \times hv = Hv$$

$$Mw = \frac{\text{mass } H_2O \text{ formed}}{\text{Btu evaporation lost}} = 50\ \frac{\text{lb } H2O}{10^6\ \text{Btu}} \quad (22)$$

Hv = heat required to evaporate formed water

i) Raise formed water vapor to stack temperature:

$$(Ha + Ho + H_Io + Hb + Hv + Haw') \quad Mw$$

$$x \; hcwv \; x \; (Ts-Tb) = Haw''$$

Haw" = heat required to raise formed water vapor to stack temperature

j) Radiation Losses:

$$hra \; x \; H_R = Hra$$

$$hra = \frac{\text{Btu radiation losses}}{\text{Btu heat available}} = 0.15$$

Hra = heat lost due to radiation

k) Total Heat Required:

$$(Ha + Ho + Haw = H_Io + Hb + Hv + Haw' + Hv' + Haw'' + Hra) = H_T$$

H_T = total heat required

4) Net Heat Available:

$$H_R - H_T = H_{NT}$$

H_{NT} = net total heat available

Table C-1 Mass and Energy Balance Results

Parameter	Moisture Content 27%	Moisture Content 20%
M_R	2000 lbm	2000 lbm
h_{CR}	5050 Btu/lbm	5750 Btu/lbm
H_R	10,100,000 Btu	11,500,000 Btu
fo	0.64	0.70
ma	12.58 $\frac{\text{lb dry air}}{\text{lb organics}}$	12.58 $\frac{\text{lb dry air}}{\text{lb organics}}$
Ma	16,110 lbm	17,620 lbm
hca	0.25 Btu/lb $^{\circ}$F	0.25 Btu/lb $^{\circ}$F
Ts	1625°F	1625°F
Ta	60°f	60°F
Ha	6,303,037.5 Btu	6,893,825
hco	0.24 Btu/lb$^{\circ}$F	0.24 Btu/lb$^{\circ}$F
Ti	60°F	60°F
Ho	480,768 Btu	525,840 Btu
fa	0.0043	0.0043
hcwv	0.5 Btu/lb$^{\circ}$F	0.5 Btu/lb$^{\circ}$F
Haw	54.775 Btu	60,252.5 Btu
f_{IO}	.10	.10
hc_{IO}	0.3 Btu/lb$^{\circ}$F	0.3 Btu/lb$^{\circ}$F
Tss	1400°F	1400°F
fw	0.27	0.20
hcw	1 Btu/lb$^{\circ}$F	1 Btu/lb$^{\circ}$F
Tb	212°F	212°F
Hb	82,080 Btu	60,800 Btu
[illegible]	970 Btu/lbm	970 Btu/lbm

Parameter	27%	20%
Hv	523,800 Btu	388,000 Btu
Haw'	381,510 Btu	282,600 Btu
Mw	50 lb $H_2O/10^6$Btu	50 lb $H_2O/10^6$Btu
Hv'	383,459 Btu	402,148 Btu
Haw"	279,279 Btu	292,915 Btu
hra	0.15	0.15
Hra	1,515,000 Btu	1,725,000 Btu
H_T	10,084,108.5 Btu	10,711,780.5 Btu
H_{NT}	15,891.5 Btu	788,219.5 Btu

ECONOMIC ANALYSIS

1) Total Capital Cost:

$C_T + C_I = C_{TC}$

C_T = Capital cost for transportation and transfer of solid waste

C_I + Capital cost for modular incineration system

C_{TC} = Totalcapital cost

2) Annualized capital cost:

$C_{TC} \times (A/P, 10\%, 15) = C_{TA}$

(A/P, 10%, 15) = Capital-Recovery Factor with a 10% discount rate and 15 year life expectancy of system = .1315 ( )

C_{TA} = annualized Capital Cost (10 TPD = 32,940/yr)

3) Total Operating and Maintenance Cost:

$C_{MT} + C_{MI} = C_M$

C_{MT} = operating and maintenance cost for transportation and transfer of solid waste

C_{MI} = operating and maintenance cost for modular incineration system

C_M = total operating and maintenance cost

4) Total Annualized Cost:

$C_{TA} + C_M = C_{TT}$

C_{TT}= Total annualized cost

5) Steam Produced:

Ms x M = Mst

Ms = mass of steam produced per ton of refuse

M = total tons of refuse processed

Mst = total mass of steam produced

6) Annual Heat Production Rate:

$$Ms_T \times \left(\frac{h_1 + h_2}{2}\right) \times 365 \frac{\text{days}}{\text{yr}} \times \frac{1\text{MBtu}}{10^6\text{Btu}} = H_T$$

h_1 = enthalpy of steam at lowest obtainable pressure of 100 psig = 1189. Btu/lbm

h_2 = enthalpy of steam at highest obtainable pressure of 280 psig = 1202.63 Btu/lbm

H_T = total annual heat production

7) Steam Production Cost:

$$\frac{C_{TT}}{H_T} = Cps$$

Cps = steam production cost

8) Electricity Produced:

$$Gr \times U \times 365 \frac{\text{days}}{\text{yr}} = G_T$$

Gr = KWH produced per ton of refuse processed. A range was given of 30-100 KWH per ton of refuse

G_T = total electricity generated

9) Electricity production cost;

$$\frac{C_{TT}}{G_T} = Cp_E$$

Cp_E = electricity production cost

Table C-2 Economic Analysis Results

rameter	Plant Capacity (TPD)				
	10	20	40	60	80
C_T	\$500	\$1000	\$2000	\$3000	\$4000
C_I	\$250,000	\$500,000	\$1,000,000	\$1,500,000	\$2,000,000
C_{TC}	\$250,000	\$501,000	\$1,002,000	\$1,503,000	\$2,004,000
(A/P,10%,15)	.1315	.1315	.1315	.1315	.1315
CTA	\$32.940	\$65,882	\$131,763	\$197,645	\$263,526
C_{MT}	\$25,000	\$25,000	\$25,000	\$25,000	\$25,000
C_{MI}	\$40,000	\$80,000	\$160,000	\$225,000	\$280,000
C_M	\$65,000	\$105,000	\$185,000	\$250,000	\$305,000
C_{TT}	\$97,940	\$170,882	\$316,763	\$447,645	\$568,526
Ms	3700 lbm/ton	3700 lbm/ton	3700 lbm/ton	3700 lbm/ton	3700 lbm/ton
M	10 TPD	20 TPD	40TPD	60 TPD	80 TPD
Ms_T	37,000 lbm/d	74,000 lbm/d	148,000 lbm/d	202,000 lbm/d	296,000 lbm/d
h_1	1189.65 Btu/lbm	1189.65Btu/lbm	1189.65Btu/lbm	1189.65Btu/lbm	1189.65 Btu/lbm
h_2	1202.63Btu/lbm	1202.63Btu/lbm	1202.63Btu/lbm	1202.63Btu/lbm	1202.63Btu/lbm
H_T	16.15×10^3 MBtu	32.3×10^3 MBtu	64.6×10^3 MBtu	96.9×10^3 MBtu	129.2×10^3 MBtu
Cps	\$6.06/MBtu	\$5.29/MBtu	\$4.90/MBtu	\$4.62/MBtu	\$4.40/MBtu
Gr	30-100KWH/ton	30-100KWH/ton	30-100KWH/ton	30-100KWH/ton	30-100KWH/ton
G_T(30 KWH/ton)	1.09×10^5 KWH	2.19×10^5 KWH	4.38×10^5 KWH	6.47×10^5 KWH	8.76×10^5 KWH
G_T(100KWH/ton)	3.65×10^5 KWH	7.3×10^5 KWH	14.6×10^5 KWH	21.9×10^5 KWH	29.2×10^5 KWH
Cp_E	\$0.78/KWH	\$0,78/KWH	\$0.72/KWH	\$0.68/KWH	\$0.65/KWH

PAYBACK PERIOD

1) Savings realized in production cost per MBtu:

$Cps' - fps\ Cps = \Delta Cps$

Cps' = conventional steam production cost

fps = correction factor for system downtime

Cps = estimated production cost for RDF ininceration system

ΔCps = difference between present cost and estimated RDF system cost

2) Annual Saving:

$\Delta Cps \times H_T = SVa$

SVa = annual savings

3) Payback Period:

$$C_{TC} \times \frac{1}{SVa} = PB$$

PB = payback period

Table C-3 Payback Period Calculation Results

Parameter	Plant Capacity (TPD) 10	20	40	60	80
Cps'	\$8/MBtu	\$8/MBtu	\$8/MBtu	\$8/MBtu	\$8/MBtu
fps (10% downtime)	1.11	1.11	1.11	1.11	1.11
fps (20% downtime)	1.25	1.25	1.25	1.25	1.25
Cps	\$6.06/MBtu	\$5.29/MBtu	\$4.90/MBtu	\$4.62/MBtu	\$4.40/MBtu
ΔCps (10% downtime)	\$1.27/MBtu	\$2.13/MBtu	\$2.56/MBtu	\$2.87/MBtu	\$3.12/MBtu
ΔCps (20% downtime)	\$0.42/MBtu	\$1.39/MBtu	\$1.875/MBtu	\$2.225/MBtu	\$2.5/MBtu
H_T	\$16.15x10^3 MBtu	\$32.3x10^3 MBtu	\$64.6x10^3 MBtu	\$96.9x10^3 MBtu	\$129.2x10^3 MBtu
SVa (10% downtime)	\$20,510	\$68,000	\$165,376	\$278,103	\$403,104
SVa (20% downtime)	\$6864	\$44,900	\$121,125	\$215,600	\$323,000
C_{TC}	\$250,500	\$501,000	\$1,002,000	\$1,503,000	\$2,004,000
PB (10% downtime)	12.2 yrs	7.3 yrs	6.07 yrs	5.41 yrs	5.00 yrs
PB (20% downtime)	36.5 yrs	11.2 yrs	8.27 yrs	6.97 yrs	6.20 yrs

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